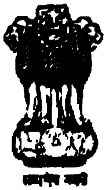

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FOREWORD

by THE RIGHT HON. HERBERT MORRISON, M.P.

Home Secretary and Minister of Home Security

ONE of the aspects of the National Fire Service to which I attach the greatest importance is the opportunity which it offers for a more equal standard of training for all, irrespective of the size of town or village in which they serve. This training is being given through the medium of the National Fire Service College at Brighton and of Training Schools set up in all parts of the country. No amount of training can replace practical experience, but a sound background of theoretical knowledge is essential to the fireman whatever his rank if he is to carry out his duties intelligently and make the best possible use of his equipment.

The formation of the National Fire Service resulted from the need to adapt our organisation and our methods to meet the problems set by the intensive incendiary air attacks on our cities. We cannot meet and defeat this menace any more than we can meet and deal efficiently with peace-time fires unless every member of the Service is highly trained and plays a full part in the organisation.

Much of the necessary knowledge can only be obtained by drill, by exercises and by oral instruction, but the written word will always play a fundamental part in the fireman's education. To ensure that the knowledge which has been acquired over the past years is made available to all, this *Manual of Firemanship* is published. It is issued in parts, for the need is great and time is short. The *Manual* will have an important place in the Service, for it will assist the recruit and will also be indispensable to those studying for promotion. Men and Women of the National Fire Service, I commend it to you.

INTRODUCTION

by COMMANDER A. N. G. FIREBRACE, C.B.E., R.N.(Rtd.)

Chief of the Fire Staff and Inspector-in-Chief

THIS *Manual* is one of the first fruits of the creation of the National Fire Service, which alone has made it possible. Firemen have always been handicapped by the fact that so few attempts have been made to present in a convenient form the technical information needed for firefighting. As a consequence, they have had to depend too much on fire "lore" which has been handed down by word of mouth from generation to generation. The necessity for a really comprehensive textbook on firemanship, to which all ranks can turn for information, can hardly be over-estimated.

It is not contended that a fireman can be made by studying a book—a fireman can only be made by riding to fires year in and year out—but the young fireman who has a sound theoretical background gained from study will profit far more from experience at fires than his less knowledgeable colleague. He will be better able to understand what he sees, and why it happens, and will find occasions when he can put to practical use the knowledge he has acquired from study.

Strength and courage will always remain vital attributes of firemen, of all ranks, but if an officer is to have the respect of those he leads he must also possess a sound technical knowledge of his profession.

Apart from its place as the standard reference book for the Fire Service, the *Manual* will prove of inestimable value to the National Fire Service College and to the many Training Schools now performing such useful work throughout the country. It is not intended to do the lecturer's work for him—but it will enable him to do his work better, to cover more ground in his allotted period and to progress to a higher standard.

The Service has always thirsted for technical knowledge and has read with avidity anything that is published on the technical side of the profession. Students of firefighting, both men and women, whole-time and part-time, will now have an authoritative source of information on which they will be able to draw, to their own advantage and the nation's benefit.

PREFACE BY THE EDITOR

A PRELIMINARY review of the work involved in the preparation of this *Manual* showed that the task was one of considerable magnitude. Nothing on this scale had previously been attempted for the Fire Service, and it was clear that to prepare the information, edit the text and arrange for the necessary illustrations would take some considerable time.

As the Home Secretary, Mr. Herbert Morrison, has said in the Foreword, time is short. The information is urgently required by the Service and to hold up publication until the whole work was completed would have been out of the question. It was therefore decided, in order to make the *Manual* available with the minimum of delay, to divide the contents into seven parts. Each has been planned so that it is as self-contained as possible and will be published as soon as it is completed. This is Part I.

The contents have been arranged in their natural order, that is, the fundamental principles which underlie firefighting are first dealt with, followed by a description of the equipment employed. From this will be developed the correct and intelligent employment of this equipment and the organisation necessary to make the best use of the resources available.

The arrangement of the *Manual* in parts, although essential from the point of view of immediate publication, necessitates occasional cross-reference to sections which are yet to come. This is unavoidable, since, in whatever order the information is presented, the book cannot be comprehensive until the whole has appeared. The reader must therefore exercise restraint if from time to time he finds a reference to material which is not yet available to him.

The *Manual* has been written as a guide to the modern principles of firefighting and to the equipment available. It is not intended to present details of operational procedure in the National Fire Service, instructions on which are issued elsewhere. Nevertheless, in order to make the information given in the *Manual* as complete as possible, certain current operational instructions such as standard tests have been included. It should be made clear that in every case where standard tests are referred to, they are those in force at the time of publication and may subsequently be changed. For guidance on operational instructions which are liable to modification in the light of experience and of new developments in equipment, etc., the service reader is referred to the current orders issued within the Service. *Information given in the Manual does not, of course, override such instructions.*

Necessity for economy in the use of paper makes it impossible to issue a separate index with each part, but it is hoped that a comprehensive index and glossary will be included as a final section. To assist the reader in finding his way about the *Manual* pending the completion of this index, a synopsis of the proposed contents of each chapter in the whole work has been included at the beginning of this part. This synopsis should, however, be treated only as a provisional guide to the proposed contents, since the preparation of the latest chapters is still in its early stages and some modification of the proposed contents may later be found necessary.

It should perhaps be made clear that the text has been very carefully edited to exclude any material which might possibly assist the enemy. As a result, details of certain specialised subjects have been restricted to a somewhat more general basis than would otherwise have been the case.

Correspondence from readers of the *Manual of Firemanship,* whether or not members of the National Fire Service, drawing attention to inaccuracies or omissions in the text is invited. Letters should be addressed direct to: The Fire Staff Officer (Publications), Home Office (Fire Service Department), Horseferry House, London, S.W.1.

No preface would be complete without a grateful acknowledgment of the ready assistance which has been received in the preparation of both text and illustrations. It would be impossible to name all who have contributed materially to its accuracy and to ensuring the comprehensiveness of the *Manual.* To the personnel within the Service, to the members of other Departments and of outside authorities, and to the many firms of Fire Service equipment manufacturers who have provided information and checked the various sections for accuracy the Home Office (Fire Service Department) extends its grateful thanks.

V. J. W.

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PART I CHAPTER I

THE PHYSICS AND CHEMISTRY OF COMBUSTION

IN order to understand the phenomena of fire and fire extinction, some knowledge of physical and chemical principles is desirable, viz., the properties of matter, and in particular the phenomena associated with the heating and cooling of materials of construction.

I. PHYSICAL PROPERTIES

The most familiar properties are those concerning size and weight. In this country size is normally measured in feet and inches, but it may also be measured in metric units. The metre (which is 100 centimetres) equals 39·37 ins. Thus 1 in. equals 2·54 cms., and 1 ft. about 30·5 cms. A kilometre (which is 1,000 metres) is equal to about ⅝ of a mile.

Weight is normally measured in lbs. and ounces, but may also be measured in metric units. The kilogram (which is 1,000 grams) equals 2·204 lbs., so that 1 lb. weighs 453 grams, and 1 oz. weighs 28·3 grams. The kilogram of water provides a unit of volume on the metric system; this is the litre (1,000 cu. cms.), a volume equal to about 1¾ pints. A gallon of water therefore equals 4½ litres; its weight is 10 lbs.

For more detailed relationships reference should be made to sets of tables.

(a) Density and Specific Gravity. The difference in heaviness is one of the most noticeable properties of materials. A child can recognise the sort of difference which enables wood to float and stone to sink in water—a difference which can be expressed in numbers as density or specific gravity.

Density may be expressed as the weight in lbs. of one cubic foot of a substance, *e.g.*, the density of water is 62·4 lbs. per cu. ft. In metric units the density of water is 1 gram per cu. cm., and of mercury is 13·6 grams per cu. cm. The term " bulk density " in lbs. per cu. ft. is a figure of practical importance in storage and transport as a guide to the space occupied by an irregular solid.

Specific gravity is the ratio of the density of a substance to the density of water which is usually taken as a standard. The specific gravity of water is 1, and of mercury 13·6.

Thus there are two methods in use for expressing " heaviness " in numbers. It should be noted, however, that it is common to express the specific gravity of gases in terms of air, *e.g.*, to say that the specific gravity of carbon dioxide is the ratio of the densities of CO_2 and air, which equals 1·46. Coal gas as usually distributed has a specific gravity of about 0·5.

Density in general life is a property of far-reaching importance, and to the fireman the densities of fluids, *i.e.*, liquids and gases—

are of particular interest. This is because fluids within the limits set by containers are free to move under the influence of gravity and as determined by density.

Thus, if water is poured into two tanks, (*a*) and (*b*) (Fig. 1), connected by a pipe at the base, the liquid will assume the same level in each because the contents of each have the same density. If, however, the water in one, say (*b*), is replaced by petrol, the level of the latter will be higher because petrol has a density of about 0·75 while that of water is 1. Moreover, if water is added to tank (*a*) the water will raise the petrol in (*b*) and eventually displace it entirely from the tank. The fact that petrol and other combustible liquids float thus on water is a well-known property of liquids which can never be overlooked in firemanship, for it increases the difficulty of fire-fighting and promotes the spread of a conflagration where liquids are involved.

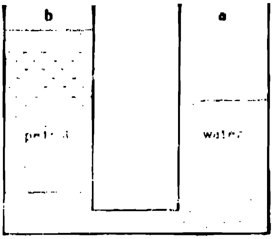

Fig. 1.

The influence of difference in density is even more important in connection with gases. Gases differ in density, and the consequences have a certain parallelism with the behaviour of petrol and water in tanks, which is exemplified by a chimney full of hot products of combustion.

The chimney may be regarded as a tank full of light, hot gas communicating at the base with another tank full of a cold gas (the surrounding outside air). Considering the gases occupying the same height—the height of the chimney—we have, therefore, two volumes of fluid of equal height but of different weight, and, therefore, unbalanced. In order to restore balance, cold air from outside flows into the base of the chimney and displaces hot gas in the chimney. This would continue until the chimney is full of cold air. In practice the process is maintained continuously by a fire at the base of the chimney which replaces the hot chimney gas which is driven from the chimney top.

If, however, the outflow of hot gas from the top of the chimney is prevented by means of a cover or damper, it will be found that a pressure has developed at the top of the chimney. The weight of the column of lighter hot gas in the chimney is insufficient to balance the weight of the heavier cold outside air. This unbalanced condition is responsible for a force which is expended in driving gas from the top of an open chimney. When the top is closed the force is found in the form of an equivalent pressure which can be calculated if the densities of the gases are known.

The density of air at normal temperatures is 0·074 lb. per cu. ft. At 572° F. the density at the same pressure would be about halved—*i.e.*, 0·037 lb., so that the difference in weight of 1 ft. cubes of the two gases would be 0·037 lb. Consider a chimney of cross-section equal to 1 ft. and height 50 ft., filled with hot gas at 572° F. and density 0·037 lb. per cu. ft. There will be an unbalanced weight from the cold outside air equal to 50 × 0·037 = 1·85 lb. operating on 1 sq. ft. of area at the top of the chimney if closed. If the chimney top is opened this force is used to drive the hot gas from the chimney. In a burning building similar conditions are developed. Inside, the air is heated, becomes lighter, rises, and escapes through any openings which may be available. If ways of escape do not exist, a pressure will be developed on the walls of the upper parts of the structure. It is easy to see that the opening of a door or window may release this pressure and in doing so allow an outrush of hot gas or flames which may involve any person acting incautiously. The effect of making such an opening is to convert the building into an open chimney, the hot gases escaping above being replaced by cold fresh air from below, which serves to intensify the fire.

Differences in density may operate in a similar way whenever gases come together. Light gases such as coal gas (specific gravity = 0·5 compared with air) will rise to a ceiling and only slowly interdiffuse in the air afterwards. Heavy gases such as carbon dioxide (specific gravity 1·46) and petrol vapours will accumulate in low places such as wells and cellars, so creating dangers of asphyxia and fire or explosion.

(b) The States of Matter. Matter may be found in three states, solid, liquid and gaseous, although some substances may be incapable of existence in all three. Water exists in all three states as ice, liquid water and steam. Although the chemical composition of all three is the same, *i.e.*, molecules comprised of two atoms of hydrogen and one of oxygen (see later), they look and behave unlike. This is due to the differences in energy content of the material, the energy being recognisable as heat. Energy may take various interchangeable forms—heat, electricity, light, mechanical energy, and even energy of position. If heat energy is taken from water by cooling, the molecules of water, which are capable of considerable mobility, become sluggish and, at a certain temperature, lose the freedom of movement they have as a liquid, and the water freezes to a solid—ice. To thaw this ice to water requires the supply of a quantity of energy which is measurable as heat. This is called the latent heat of fusion of water and equals 80 calories per gram, or 144 British Thermal Units (usually abbreviated to B.Th.U.) per lb. (see later, under (*c*) Heat and Temperature for an explanation of these units).

If more energy is put into the water, changes take place which are immediately perceptible. The water becomes hotter, and "thinner," or less viscous—due to the increased mobility of the molecules. It will swell or increase in volume, but this is also true of solids. Some of the more highly energised molecules at the surface will actually escape into the space above the surface as vapour. This evaporation becomes more pronounced as more energy is added to the liquid. Eventually a point is reached at which the liquid material becomes wholly dispersed in a new form, which is known as the gaseous state.

When this takes place the material is said to boil, and the temperature at which it occurs is called the boiling point. To cause a liquid to boil requires an almost complete loosening of the bonds linking the molecules together and a correspondingly large addition of energy. The necessary energy—the latent heat of evaporation—amounts to 540 calories per gram of water at the normal boiling point or 973 B.Th.U. per lb.

It should be noted that the latent heat of vaporisation of water is much larger—nearly seven times greater—than the latent heat of fusion. This can be understood when it is considered that the dispersal of a mass of water into a large volume of steam is a much more drastic process than the loosening of the molecules of water from the solid state as ice to water where no large expansion is produced. After complete conversion of water to steam any further addition of energy reveals itself by a large increase in volume or, in a closed vessel, by rise of pressure. When water is heated in a closed vessel a pressure gauge will register a rise in pressure, but no visible change will be apparent. A layer of steam will form over the water but, apart from a difference in the proportions of the two layers there will be no visible change at first. Eventually, however, a point is reached at which the line of demarcation between the lower layer of liquid and the upper layer of steam vanishes—in other words the distinction between liquid and gas disappears. It is possible about this point (the "critical temperature") for the water to become steam without the change of volume which we associate with boiling. This critical temperature is associated with a certain critical pressure, both of which are characteristic of the material itself.

(c) Heat and Temperature. The above paragraph summarises the physical changes of normal materials as their energy content is increased from the lowest temperatures to very high ones. The solid material at the freezing point changes into a liquid. At the boiling point this changes into a vapour and at the critical point the distinction between a liquid and gas disappears. These changes are, however, brought about by changes of energy content of the molecules and point to the distinction between heat and temperature.

Boiling water is hotter than freezing water because of its higher heat content, and this difference of heat content can be used to make a scale of temperature. If the difference in "hotness" is called 100 units, the centigrade scale of temperature is created, if 180 units the fahrenheit scale is obtained. The fixed points on the centigrade scale for the freezing and boiling points of water are 0 deg. and 100 deg. As the figure for the freezing point of water was chosen as 32 deg. on the fahrenheit scale, the boiling point becomes $100 \times \frac{180}{100} + 32$ deg., or 212 deg. The rule for the conversion of temperatures from one scale to the other is thus obviously :—

Degrees centigrade multiplied by $\frac{9}{5} + 32$ give degrees fahrenheit.

Degrees fahrenheit $- 32$ multiplied by $\frac{5}{9}$ give degrees centigrade.

There is a considerable looseness in the use of the words heat and temperature. In speaking of furnaces in industry the word heat is often used in the sense of temperature. It is preferable to avoid using these words in a sense liable to cause confusion. The matter bears some analogy to the difference between height and potential energy of position. If a quantity of water is raised above sea-level, it will acquire energy which, by some sort of water mill, could be recovered as useful work. The greater the height, the greater the work obtainable. In this example, the total quantity of energy is clearly dependent on two factors, viz. height above sea-level and quantity of water, and there is no confusion between the two. It follows at once that a definition can be given for a unit of heat. In centigrade units the unit of heat is taken as the quantity of heat which will suffice to raise the temperature of 1 gram of water through 1 degree centigrade. A British Thermal Unit (usually abbreviated as B.Th.U.) is the quantity of heat which will raise the temperature of 1 lb. of water through 1 degree fahrenheit.

It is now appropriate to consider the influence of heat and temperature on some of the properties of matter likely to be of interest in connection with firefighting.

(*d*) *Size*. Generally speaking, matter which does not change in composition or porosity, increases in size when heated. The increase in size per degree rise in temperature is defined by the "coefficient of expansion." If the size is measured in length, the coefficient is called linear, and linear coefficients are used when solids are in question. When dealing with liquids or gases, it is more convenient to measure volumes and to state the expansion in terms of "cubic coefficients." In all cases the scale of temperature should be stated. Therefore, the coefficient of expansion of a substance is the increase in size (length or volume) of 1 unit (length or volume in chosen units) when heated through 1 deg. of temperature (centigrade or fahrenheit). In tables, figures are usually given in the centigrade scale.

The linear coefficient of expansion of iron is given as 0·0000055 per 1° F., which would imply that a piece of iron 10 ft. long, on heating to 1832° F., gains in length by about 10 × 0·000005 × 1832, or 0·1 ft. (*i.e.*, about 1¼ ins.). Such calculations should be used with caution as these coefficients hold good only over a limited range and may vary considerably, sometimes quite abruptly. For instance, silica, of which sand and many building materials are composed, undergoes a sudden expansion when heated to 1067° F. Constructional materials almost invariably show considerable differences in expansion relative to one another when heated through a considerable temperature range resulting in probable damage to rigid structures. Instances of differential expansion which may have desirable or undesirable results are common.

The relatively high coefficient of expansion of aluminium is conducive to the seizing of aluminium pistons in cast-iron engine blocks, when new and well-fitting engines are being run in. Invar metal, an iron-nickel-steel, has a coefficient which is almost nil, and is used for making rules and tape measures because the length is scarcely affected by ordinary temperature changes.

Bimetallic strips formed of metals with different coefficients of expansion become deformed on heating, the deformation being proportional to the change in temperature. Such devices are found in common use in the construction of automatic fire alarms and controlling mechanism. The thermostatic device, *i.e.*, the apparatus for maintaining the temperature of an object at the desired figure, is frequently operated by the differential expansion of two pieces of metal of different thermal expansion. Many other examples could be quoted.

The expansion of liquids or gases is usually reckoned in terms of volume, for obvious reasons. The swelling of a suitable liquid provides the means of constructing a scale of temperature defined in terms of the freezing and boiling points of water. Water itself is not a convenient liquid for this purpose and in practice it is normal to use the expansion of mercury in a thermometer. The mercury is confined in a bulb attached to a glass tube of fine bore. The positions where the mercury thread ends when the thermometer is immersed first in ice and then in steam are marked. The distance between these two points is divided into 100 parts, and each part then indicates a change of 1 degree of temperature on the centigrade scale.

(e) Heating and Cooling. It is desirable to form a quantitative picture of the process of heating and cooling, taking into account the significance of the term heat and temperature.

Sometimes material can absorb heat without showing signs of a rise of temperature, *e.g.*, ice can be melted by the addition of warm water without any noticeable rise in temperature. On the other hand the heating of water produces a noticeable rise in temperature. For this reason, sometimes a distinction is drawn between latent heat of the first kind and sensible heat which can be felt.

Sensible heat which can be felt is generally more easily comprehended and provides a means of definition. The unit consists of the quantity of heat which will raise the temperature of 1 gram of water through 1° C., and is called the calorie. Sometimes the unit is defined in terms of the kilogram of water, called the kilogram calorie. In British units, as mentioned above, the B.Th.U. is the quantity of heat which will raise the temperature of 1 lb. of water through 1° F. The kilogram calorie is almost exactly equal to 4 B.Th.U.

Now there are marked differences in the capacity of different materials for absorbing heat, and these are related to the structure of the matter itself. Water is an example of a substance which absorbs relatively large quantities of energy during change of physical condition. Rise of temperature is produced by the addition of sensible heat, and must be related to the capacity of the material to absorb heat—a quantity called its specific heat. It will be noticed from the figures given that the specific heats for all other substances are less than that of water—some very much lower. Water in form of steam has a specific heat of only 0·48. Organic substances such as petrol, alcohol, etc., all have small specific heats. This means that such materials when supplied with a given quantity of heat show a much greater rise of temperature than water. They are also readily vaporised and have low flashpoints or emit poisonous vapours. It is clear that low specific heats are of considerable importance in promoting fire risks.

The latent heats of fusion and evaporation of water are also high relative to those of other common substances. It requires more energy to change the state of ice to water and water to steam than substances like paraffins, alcohols and benzole. It should also be noted that freezing occurs at a fixed temperature and the latent heat is, therefore, a constant ; vaporisation can occur at all temperatures up to the critical temperature when the distinction between gas and liquid disappears. What is called the boiling point is merely the temperature at which a liquid emits vapour at a pressure equal to the existing barometric pressure. The latent heat of vaporisation varies with the temperature at which boiling takes place and diminishes as the temperature rises. For example, if water is evaporated at air temperature, the latent heat is 585 calories per gram (1055 B.Th.U. per lb.) and at 212° F. it is 540 calories per gram (972 B.Th.U. per lb.), whilst at 705° F., the critical temperature when the distinction between gas and liquid vanishes, it will become nil. Any heat imparted to water above this temperature must raise both the temperature and the pressure.

The existence of critical points has considerable importance in connection with fire hazards, because of the quantity of compressed gases in commercial use. Some of these have critical points near and above normal air temperature. Carbon dioxide in liquid form is stored, transported and used compressed in cylinders. Its critical temperature—87° F.—is only a little above our air temperature. It would require no great rise of temperature during a fire to bring a cylinder of liquid carbon dioxide above the critical temperature when all the heat absorbed would be effective in raising the temperature and pressure of the carbon dioxide. Pressures would rise rapidly and increase the hazard of explosion. Carbon dioxide has one merit, that it is an effective agent for extinguishing fires. Where poisonous compressed liquid gases such as chlorine, ammonia and sulphur dioxide are in question, the consequences of overheating the cylinders in which they are contained may be serious.

The high latent heat of vaporisation is a valuable property of water in its application to firefighting. Water is the most useful and abundant agent for the extinction of fire—for which an essential property is a large capacity for heat absorption—and in addition to its abundance and availability, water has the greatest capacity for heat at all temperatures which come into question. Water will absorb 85 calories per gram (153 B.Th.U. per lb.) in being heated from air temperature to the boiling point. It will, however, absorb 540 calories per gram (972 B.Th.U. per lb.) in conversion to steam at the boiling point. It is clear from these figures that water will be used most efficiently for fire extinction if it can be converted into steam. Cold water draining away from a conflagration has played a negligible part in extinction.

1. CHEMICAL PROPERTIES

Both chemical and physical processes enter into ignition and the growth and extinction of fire. It is, therefore, desirable that every fireman should possess some knowledge of the chemistry of fire.

A fire is normally produced by the burning of some fuel with air. Air consists substantially of a mixture of gases, 79 per cent. by volume of air being nearly pure nitrogen—an incombustible gas and an inert diluent which plays no part in the combustion process. The remaining 21 per cent. by volume is oxygen, a gas essential to combustion and life. Oxygen is slightly heavier than nitrogen and so forms 23 parts of the air by weight.

The essential constituents of nearly all useful fuels are carbon and, to a less extent, hydrogen. Both are elements, *i.e.*, one of the ultimate components of all matter. They readily burn on combining with oxygen and in so doing set free large quantities of heat. Chemists are accustomed to depict these chemical processes by means of a sort of shorthand of symbols and equations. Each element has a distinctive symbol. The smallest particle of an element capable of existence is called an atom. The atoms of different elements differ in weight, and hydrogen is the lightest element.

Each of these elements has a definite symbol, thus H represents hydrogen, O represents oxygen, Cl represents chlorine, and so on. This symbol is usually taken from the Latin name, thus lead is Pb from Plumbum, tin is Sn from Stannum, and so on. A second letter is used where necessary to prevent confusion between elements having similar initial letters. Thus Cl = chlorine whilst C = carbon. The atomic weight of hydrogen being taken as 1 (since it is the lightest element), that of carbon is 12, of oxygen 16, and of nitrogen 14.

The atoms of many elements cannot exist alone but seek partners with either another atom of the same or different element. It is this urge to link up with other atoms as a result of chemical forces which gives rise to " chemical reaction " with all its practical consequences.

Hydrogen, nitrogen and oxygen are all gaseous elements. Under normal conditions two atoms of each link up with each other to form a stable combination called a molecule, *i.e.*, the smallest compound of the two capable of permanent separate existence. In chemical shorthand this is indicated by a small suffix giving the number of atoms present in one molecule. The molecules of hydrogen, nitrogen and oxygen are written H_2. N_2 and O_2, and their molecular weights are, therefore, 2, 28 and 32, *i.e.* just double the corresponding atomic weights.

It will be noted that the absolute weights of the atoms and molecules are not normally used but only a number proportionate thereto. As chemical and physical processes involve matter in the form of atoms and molecules, it is convenient to calculate in terms of atomic and molecular weights. For instance, the density of a gas is proportional to its atomic or molecular weight at a given temperature and pressure. The space occupied by a " gram molecular weight " of gaseous molecule is the same for all gases at the same temperature and pressure, and many other properties are related to the atomic or molecular weights. Thus 2 grams of hydrogen, 28 grams of nitrogen and 32 grams of oxygen all measured at 32° F., and 76 cms. of mercury pressure (normal temperature and pressure usually abbreviated as N.T.P.) all occupy 22·4 litres of space—a volume called the gram molecular volume. By a remarkable and accidental coincidence the same number applies in the British system of weights and measures, provided that weights are stated in ozs. and volumes in cu. ft. Thus 28 ozs. of nitrogen and 32 ozs. of oxygen gas both occupy 22·4 cu. ft. at N.T.P. In the pages which follow, weights, volumes and heat quantities will usually be stated in British units.

PROCESS OF COMBUSTION

Having defined the terms and the symbols used in chemical shorthand, it is now possible to consider what happens in combustion processes, and how these are depicted on paper by means of chemical formulæ and equations.

I. THE COMBUSTION OF CARBON

The first and probably most important example is the combustion of the solid element carbon, the purest form of which is the diamond. Graphite is another form, and less pure forms are found in coke, charcoal and lamp black. Carbon enters into the composition of most commercial fuels. When carbon is heated in contact with air, at some temperature which depends on the nature of the carbon and condition of the heating, the oxygen and carbon combine to form carbon dioxide, a colourless gas, heavier than air. Although this gas does not support life or combustion, it is not actively poisonous, for it forms a considerable part of the air exhaled from the lungs in normal respiration. It is also used for aerating beverages.

(a) Reaction of Carbon with Oxygen. The combination, or reaction, of carbon with oxygen takes place rapidly, indeed at a red heat just as fast as the oxygen reaches the surface of the glowing carbon. The process is depicted by the chemical equation :

	$C + O_2 = CO_2 + 10{,}890$ B.Th.U. for 12 oz. of carbon. . . . (1)
Weight in oz. .	$12 + 32 = 44$
Vol. in cu. ft. at N.T.P. . .	22·4 22·4
Heat of reaction.	10,890 B.Th.U. liberated per 12 ozs. of carbon, or 14,520 B.Th.U. per 1 lb. of carbon.

This equation means that 1 atom of carbon (C) + 1 molecule containing 2 atoms of oxygen (O_2) react or combine to form 1 molecule of carbon dioxide (CO_2). The carbon is a solid and in the solid state it is necessary to reckon with atoms only. Independent molecules do not exist in the solid state. Assuming a knowledge of atomic weights, the equation shows that 12 ozs. of carbon combine with 32 ozs. of oxygen to give 44 ozs. of carbon dioxide gas. It indicates, furthermore, that this process is accompanied by the liberation of a large quantity of heat, *i.e.*, 10,890 B.Th.U.

Care must be taken to differentiate between a true chemical reaction as illustrated above and a simple mixing without chemical reaction. When oxygen is mixed with nitrogen to form air the liberation of heat is negligible, for the components remain unchanged in form, weight and composition. When, however, a chemical change takes place the weight of matter also remains the same. Thus in this simple case of combustion from 12 ozs. of carbon and 32 ozs. of oxygen, 44 ozs. of product are obtained, but the form of the original components can no longer be recognised. There is a rearrangement of atoms in the new molecules produced. These have a smaller energy content and the difference is set free as heat. It is normal in chemical reactions which involve a rearrangement of atoms and consequent change in the energy content of the matter to find either a liberation of heat to, or absorption of heat from, the surroundings. Commercial fuels are essentially materials which, when reacting with oxygen, yield much energy in the form of heat, although it should not be overlooked that the energy may be obtained in other forms, *e.g.*, electricity and light. Equation (1) also implies that 12 ozs. of carbon combine with 22·4 cu. ft. of oxygen to yield the same volume of carbon dioxide.

These figures show the advantages of calculating in molecular units. Volumes of gases are then always multiples of 22·4 cu. ft. Calculations of heat quantities are facilitated. Nevertheless, it is often convenient to calculate the quantity of heat generated by 1 unit of weight—*e.g.*, 1 lb. Thus the calorific value of heat generated per oz. of carbon burnt to carbon dioxide equals one-twelfth of 10,890 B.Th.U. the heat liberated by the combustion of 1 oz. atom of carbon, *i.e.*, $\frac{1}{12} \times 10{,}890$ or 910 B.Th.U. This amounts to 14,520 B.Th.U. per lb.

(*b*) *Reaction of Carbon with Carbon Dioxide.* Equation (1) depicts the relation between heated carbon and carbon dioxide when free oxygen is present. When oxygen is not present, another type of chemical process can occur above a red heat, viz. :—

$$C + CO_2 = 2CO - 4390 \text{ B.Th.U. for 12 ozs. of carbon} \quad . \quad . \quad . \quad (2)$$

Weight in oz. . $12 + 44 = 2 \times 28$
Vol. in cu. ft. at N.T.P. . . 22·4 2×22·4
Heat of reaction. 4390 B.Th.U. absorbed per 12 ozs. of carbon or −5815 B.Th.U. per 1 lb. of carbon.

If carbon is heated and kept red hot in contact with carbon dioxide, a chemical reaction takes place whereby the 2 atoms of oxygen are shared between 2 atoms of carbon to yield a new gas, carbon monoxide. This is colourless, without smell, but actively poisonous when inhaled. The red cells in the blood, which convey oxygen throughout the body, combine very readily with the carbon monoxide forming a relatively stable compound. The blood carries this instead of oxygen throughout the tissues of the body, which suffer from oxygen starvation, leading to collapse and ultimately death. The conditions leading to the formation of carbon monoxide occur very frequently in practice, *i.e.*, whenever red-hot carbon and carbon dioxide gas meet in the absence of free oxygen. This occurs in every bed of burning solid fuel, such as coal, coke or charcoal, which is more than a few inches thick.

When air passes through a bed of glowing carbon the whole of the oxygen is converted into carbon dioxide by the reaction depicted in equation (1). As the gases rise more than about 4 ins. in contact with red-hot carbon the carbon dioxide, as stated above in equation (2), is converted into carbon monoxide which may be recognised by the appearance of a blue flame at the top of the fuel bed. If conditions are such that oxygen is not available above the fuel bed, or the temperature is too low, the carbon monoxide will not be able to catch fire. It may pass on unnoticed wherever the products of combustion go. This may be a source of danger to those whose work brings them into places where conditions for the formation of carbon monoxide exist.

Coal gas contains 5 to 10 per cent. of carbon monoxide and is well known as a poisonous agent. The process depicted in equation (2), as described above, is used in the "gas producer", which consists of a deep fuel bed in which carbon monoxide is produced, and then led away to be burnt as and when required as a fuel for furnaces or for power generation in a gas engine.

Equation (2) differs in one important respect from equation (1). Whereas in the former the reaction takes place with the liberation of much heat, in the latter to convert 44 ozs. of carbon dioxide into 2 × 28 or 56 ozs. of carbon monoxide, energy must be supplied from outside. This energy measured as heat amounts to 4390 B.Th.U. for 44 ozs. of carbon dioxide reduced to carbon monoxide.

Exothermic and Endothermic Reaction. The energy changes in chemical processes are of great practical importance and are due to the rearrangement of atoms to form new molecular structures. The combustion of fuels for the production of useful heat is always obtained by a chemical reaction accompanied by the liberation of heat of which the combustion of carbon with oxygen as shown in equation (1) is an example. This is termed an "exothermic" reaction. The heat evolved, unless dissipated to the surroundings, will cause the material, *e.g.*, the carbon of a solid fuel, to rise in temperature, as can be noticed in any fuel bed.

When, as exemplified by equation (2), it is necessary to supply energy to rearrange the atoms to form a new molecular structure, the process is termed "endothermic." Thus heat must be supplied to red-hot carbon in order to support its conversion to carbon monoxide according to equation (2). If the heat necessary is not supplied from outside, it will be taken from the carbon and carbon dioxide, the temperature of which must fall until the process is stopped. There is thus possible a cooling by chemical process independent of the normal physical cooling.

(c) Reaction of Carbon with Steam. Here it is appropriate to call attention to a somewhat similar process which occurs when steam comes into contact with red-hot carbon as shown in equation (3) below.

$$\underset{}{C} + \underset{\text{(steam)}}{H_2O} = CO + H_2 - 3260\ \text{B.Th.U. for 12 ozs. of carbon} \quad \text{(3)}$$

Weight in oz. .	$12 + 18 = 28 + 2$
Vol. in cu. ft. at N.T.P. .	22·4 22·4 22·4
Heat of reaction.	3260 B.Th.U. absorbed per 12 ozs. of carbon, or—4350 B.Th.U. per 1 lb. of carbon.

Here the carbon is able to take oxygen from the steam, producing carbon monoxide and setting hydrogen free. A bright-red heat (about 1750° F.) is necessary to obtain a result as indicated by equation (3). At lower temperatures carbon dioxide also is formed in some quantity. It is necessary to supply energy to the system to bring about this decomposition of steam, *i.e.*, 3260 B.Th.U. for 12 ozs. of carbon or for 18 ozs. of steam decomposed, and 4350 B.Th.U. per 1 lb. of carbon used. In this respect the process resembles the decomposition of carbon dioxide by carbon. It is " endothermic." This reaction must play some part in firefighting. When water is thrown upon glowing carbon, *e.g.*, charcoal, or carbonised timber, some water must be evaporated to steam which will be superheated until at some temperature above a red heat decomposition takes place according to equation (3). In so far as this happens, heat may be taken from the glowing carbon but the process would cease when the temperature falls below a red heat. The calculation above, it should be noticed, has been made on the assumption that steam is used. If liquid water is used the cooling would be greater by about 30 per cent. (see above under " Heating and Cooling ").

While this chemical cooling of the fuel bed has some advantage, it is only gained at the expense of turning the solid carbon into a mixture of two inflammable gases, one of them actively poisonous, with all attendant disadvantages. Thus the inflammable gases may rise and ignite on meeting the necessary air elsewhere and so help to spread the fire.

A mixture of carbon monoxide and hydrogen produced by the decomposition of steam by red-hot carbon is known as " water gas " and is extensively used in industry.

The important fuel gas hydrogen burns with oxygen according to the equation (4) to form steam.

$$2H_2 + O_2 = 2H_2O + 13{,}050\ \text{B.Th U per 4 ozs. of hydrogen} \quad \text{(4)}$$

Weight in oz. .	$2 \times 2 + 32 = 2 \times 18$
Vol. in cu. ft. at N.T.P. . .	$2 \times 22{\cdot}4$ 22·4 $2 \times 22{\cdot}4$
Heat of reaction.	13,050 B.Th.U. liberated per 4 ozs. of hydrogen, or 52,200 B.Th.U. per 1 lb. of hydrogen.

Unlike the combustion of carbon, the burning of hydrogen with oxygen involves gases only, and the materials combine in simple volumetric proportions, *i.e.*, 2 volumes of hydrogen and 1 volume of oxygen gives 2 volumes of steam. The reaction is strongly exothermic. The atom of hydrogen is the lightest of all elements and for equal weight the heat liberated in its combustion is the greatest. The figures given relate to the production of steam. If this were cooled to water at air temperature, the figure, 13,050 B.Th.U., would be increased by 2250 B.Th.U.—the so-called latent heat set free by condensation to liquid water.

2. REACTION OF METALS

Most elements will combine with oxygen to form compounds with oxygen or oxides under some conditions. The behaviour of metals in this respect is particularly important. In the case of common metals such as iron, copper, zinc, etc., this chemical reaction is slow at normal air temperatures and only noticeable as rusting or corrosion. At higher temperatures, however, all these metals will burn in air or oxygen in a manner similar to that of carbon. In some cases, however, the burning of the metal is continuous only if steps are taken to keep the temperature of the metal high enough. Cutting and welding steel with the oxy-acetylene blowpipe makes use of the burning of iron with oxygen at a very high temperature. On the other hand the metal sodium at air temperature combines with oxygen readily and also rapidly decomposes cold water.

Magnesium is another example of a metal which readily burns, so much so that burning magnesium ribbon is used by photographers to provide a bright light for a " flash " exposure. The ribbon can be ignited with a match. At air temperature, magnesium metal and alloys of the electron type are so stable as to be much and increasingly used in moulded mechanical construction. If heated to a temperature approaching a red heat—say about 1112° F.—the metal may burst into flame as a result of combustion with air to form solid magnesium oxide or magnesia. On account of this ease of ignition, magnesium and its alloys are used for the construction of incendiary bombs. The process may be represented by equation (5).

$$2Mg + O_2 = 2MgO + 32{,}790 \text{ B.Th.U. per 48 ozs. of magnesium} \quad \ldots\ldots (5)$$

Weight in oz. .	$2 \times 24 + 32 = 2 \times 40$
Vol. in cu. ft. at N.T.P. . .	22·4
Heat of reaction.	32,790 B.Th.U. liberated per 48 ozs. of magnesium or 10,930 B.Th.U. per 1 lb. of magnesium.

There are certain differences to note between the combustion of magnesium and that of carbon. The heat liberated per lb. of carbon is 14,520 B.Th.U., whereas magnesium furnishes only 10,930 B.Th.U.—about 24 per cent. less. Now a reasonably good house coal has a calorific value of over 14,000 B.Th.U. per lb.; thus in comparison magnesium is only a low-grade fuel. Carbon is a solid at any ordinarily attainable temperature and burns to give an invisible gas carbon dioxide. Magnesium boils at 2012° F. and the vapour formed, when burning in air, gives a flame charged with white smoke of magnesia (the oxide of magnesium). When formed at a high temperature this smoke emits a very bright light which gives an impression of heat which is not borne out by measurements. In fact, the smoke on cooling down obstructs the radiation from burning magnesium. The bulky coating of magnesia formed on the surface of burning magnesium also hinders the transmission of heat to objects which come into contact with the metal. These properties work in such a way as to diminish the effectiveness of burning magnesium as a heating agent.

The brilliant light emitted by the flame of burning magnesium or its alloys such as electron metal is deceptive. As mentioned above, 1 lb. of carbon or coal burnt generates much more heat than 1 lb. of magnesium. The carbon, however, is converted completely into invisible carbon dioxide gas which carries nearly all the heat away. This is not apparent to the eye and so the radiation from the solid fuel is only a minor portion of the heat generated. When magnesium burns the whole of the material remains as a single solid product in a new form. The heat of combustion is almost entirely used to raise the temperature of this magnesia to a very high figure. This is an example where the violence of a chemical process and the accompanying bright light is not to be taken as measuring the quantity of heat produced in the process.

Magnesium, like many other metals, decomposes water. Sodium does this rapidly at air temperature but magnesium requires a high temperature before the process becomes equally rapid, just as it must be heated to a high temperature to burn in air.

The action of water on hot magnesium may be represented by the equation (6).

$$Mg+H_2O=MgO+H_2+8550\ \text{B.Th.U. for 24 ozs. of magnesium} \quad \ldots\ldots \quad (6)$$

Weight in oz. .	24 +	18 =	40 +	2
Vol. in cu. ft. at N.T.P. . .		22·4 (as steam)		22·4
Heat of reaction.	8550 B.Th.U. liberated per 24 ozs. of magnesium, or 5700 B.Th.U. per 1 lb. of magnesium.			

Equation (6) may be compared with equation (3) which depicts the action of steam on red-hot carbon. Although they look similar, there are two important differences. The solid carbon is converted into gaseous carbon monoxide, while magnesium metal gives solid magnesium oxide. The decomposition of steam by carbon is endothermic, heat is absorbed and so the reaction is self-cooling. The corresponding action of magnesium is exothermic and the considerable evolution of heat helps to conserve the high temperature of the burning metal. If the magnesium is burning in air, the liberation of heat by the decomposition of added steam will therefore promote the combustion with oxygen. The consumption of magnesium by combustion with oxygen will be increased by the action of steam. If, however, the water is supplied at a rate exceeding that required by equation (6), *i.e.*, $\frac{18}{24}$ or $\frac{3}{4}$ of the weight of magnesium capable of reacting with water, the excess of water can only cool the metal. Persistent addition of water at an adequate rate must eventually cool the metal below its ignition temperature and cause extinction. This explains why a gentle spray of water will promote the combustion of burning magnesium, while a powerful jet of water in excess of what can react with the metal cools the metal until it becomes extinguished.

3. EXPLOSIVES

In all the examples previously quoted, combustion takes place between the fuel and free gaseous oxygen of the air. There are, however, many other chemical processes in which the reaction takes place between solids, one of which contains oxygen in combination. This includes the important class of explosives, which sometimes consist of a single compound rich in oxygen.

(*a*) *Gunpowder.* A good example is black gunpowder, which consists of an intimate mixture in suitable proportions of charcoal, sulphur and nitre or potassium nitrate—*i.e.*, in chemical symbols C, S and KNO_3. When nitre is heated with carbon or sulphur, the latter readily combine with the oxygen in the nitre, forming the gaseous oxides of carbon and sulphur, but at air temperature, mixture of the three may remain apparently inert indefinitely. Intimately mixed in suitable proportions the three are sensitive to shock or heat, giving rise to a rapid reaction, and the formation of a large volume of gas. This sudden generation of a large volume of gas and consequent development of high gas pressure is the source of the blast of explosions.

Explosives are usually solid and the sudden conversion of any solid to gas naturally involves a large increase in volume. Thus equation (1) shows that the conversion of 12 ozs. of carbon to carbon dioxide means an increase in volume to 22·4 cu. ft. Commercial explosives vary in the speed at which the solids react and are converted into gaseous products. Propellant explosives, *e.g.*, black gunpowder, and cordite and mining explosives are so constituted as to develop the maximum pressure relatively slowly. High explosives are chosen so as to secure the highest possible rate of combustion or decomposition, and the most rapid conversion of solid into gas with development of pressure, and, therefore, shattering effect or blast.

(*b*) *Picric Acid.* Some of the most effective explosives are single compounds such as picric acid and trinitrotoluene or T.N.T. Picric acid has a chemical composition represented by the formula $C_6H_3N_3O_7$, which implies a large and complicated molecule containing 47 per cent. of oxygen arranged in close contact with 32 per cent. of combustible carbon and hydrogen.

This is an unstable system liable under the influence of heat and shock to develop a sudden chemical reaction even in the absence of air, generating a large volume of carbon dioxide and steam with shattering effect. The explosion of picric acid, gunpowder, etc., is a process of chemical combustion within the solid material and independent of the oxygen of the air. It is exothermic. Considerable heat is set free as is usual in chemical processes where molecules of unstable structure are transformed into more stable products. In comparison with useful fuels, however, the heat so generated is small.

Thus 1 lb. of good coal may generate up to 14,000 B.Th.U., whereas 1 lb. of picric acid on explosion generates only 4860 B.Th.U., and 1 lb. of T.N.T. generates only 6360 B.Th.U. These figures are given to show that the violence of a destructive action is not simply measured by the quantity of heat developed. In the case of explosives the time taken to complete the chemical reaction determines the degree of blast effect.

(c) *Thermite Reactions.* There is another type of reaction between solids which is of considerable importance—the so-called " thermite " processes. Metallic aluminium shows a great affinity for oxygen. Even in contact with cold air it very readily forms a film of aluminium oxide Al_2O_3. If an intimate mixture of aluminium powder with oxides of heavy metals such as iron is heated even locally, a violent chemical reaction starts and passes through the mixture quickly. Oxide of iron, for instance, is deprived of its oxygen and molten iron is left. The aluminium is converted into fused aluminium oxide as shown in equation (7).

$$2Al \quad + Fe_2O_3 \quad = Al_2O_3 + 2Fe + 20{,}670 \text{ B.Th.U. for 214 ozs. of thermite.} \qquad (7)$$

Weight in oz. $(2\times27)+(2\times56+3\times16) \quad =(2\times27+3\times16)+(2\times56)$

Heat of reaction. 20,670 B.Th.U. liberated per 214 ozs. of thermite, or 1550 B.Th.U. per 1 lb. of thermite.

The product of a thermite reaction acquires a very high temperature and emits a bright light. It will appear surprising that this is produced by so small a quantity of heat. One lb. of thermite mixture generates 1550 B.Th.U., a quantity of heat developed by the combustion of about 1⅛ ozs. of good coal. It will be noticed, however, that no gases are produced in the reaction to dissipate the heat developed. The heat is all retained by the products of reaction which consist of molten aluminium oxide and metallic iron. As these attain a temperature estimated to be in the region of 4892° F. they naturally radiate a brilliant light. Nevertheless, the quantity of heat responsible for these effects is small in comparison with that produced by the same weight of coal or coke. Although much more is developed in the combustion of a given weight of coal, this heat is carried away by the products of combustion and is not apparent to the eye. The heat developed in a thermite process is used almost entirely in raising the temperature of the original weight of material which remains in its new form. This is another example where the violence exhibited by a chemical process and accompanying bright light is no guide to the quantity of heat produced in a process.

4. SOLID FUELS

(*a*) *Coals.* Useful lessons can be gained by consideration of the behaviour of commercial fuels. In Table I are given the composition and properties of six typical fuels.

The fuels selected are :—

1. A bituminous coal, *i.e.*, a coal which on being heated forms tarry or bituminous products. Such coals are rich in " volatile matter " and are by far the commonest type of British fuel. They differ widely in composition and properties and are also often divided into two types : (*a*) coking coals which, when heated in the absence of air, yield a strong coherent coke, and (*b*) non-coking coals which give a weak friable coke or only a loose powder.
2. A smokeless steam coal, one low in " volatile matter " which will burn with little or no smoke. Such coals were once much prized for naval purposes. They are produced in South Wales but are less generally available than bituminous coals.
3. Anthracite, a smokeless fuel but more particularly used for domestic purposes.

4. and 5. A low-temperature coke and a high-temperature coke, produced in gas retorts, both made from the bituminous coal (1).

6. A heavy mineral fuel oil such as is used for boiler firing which is included for comparison.

In the first place are given the " proximate analyses " of these fuels. Usually, these are the only tests, if any, made on fuels. The proximate analysis does not give information about the proportions of the component elements. It tells how much of the fuel is useless incombustible (the ash and moisture) and how much remains as potentially useful combustible.

In fuel of all classes the proportions of ash and moisture vary considerably according to the quality of the particular sample. The figures given in Table I are not necessarily characteristic of the class of coal. Sometimes coals naturally contain less than the figures given, or have the ash reduced by washing. Low-grade unwashed boiler slack may contain 20 per cent. of ash, or even more. Excessive ash not only lowers the heating value of the fuel but causes trouble in the fire, especially if the ash melts easily to form clinker which chokes the fuel bed.

The moisture content of coals may also vary considerably above and below the figures quoted, depending on the natural moisture of the coal and on the quantity of water it has picked up in washing or from rain. Such moisture lowers the heating value of the fuel, but is less objectionable than excessive ash. The combustible part is further sub-divided into " volatile matter " and " fixed carbon." The proportion of volatile matter is one of the most important

TABLE I

	Coal			Coke		Mineral fuel oil
	Bituminous (1)	Smokeless steam (2)	Anthracite (3)	Low temp. (Dry) (4)	High temp. (5)	(6)
PROXIMATE ANALYSIS :						
Combustible						
Volatile matter .	34·3	14·5	6·0	10·0	2·3	100
Fixed carbon . .	56·6	75·5	80·9	78·9	84·4	—
Incombustible						
Moisture . .	1·5	2·0	2·0	—	0·6	—
Ash . . .	7·6	8·0	2·1	11·1	12·7	—
ULTIMATE ANALYSIS :						
Carbon . . .	76·8	78·4	85·7	80·5	83·0	83·5
Hydrogen . .	4·9	4·1	4·1	2·4	0·4	11·7
Sulphur . . .	1·7	2·2	1·3	1·6	1·2	3·2
Oxygen . . .	5·8	4·1	3·6	2·8	1·0	1·4
Nitrogen . .	1·7	1·2	1·2	1·6	1·1	
Moisture . .	1·5	2·0	2·0	—	0·6	—
Ash . . .	7·6	8·0	2·1	11·1	12·7	0·2
Cal. value B.Th.U. per lb. gross . . .	13,600	13,780	14,500	13,000	12,600	18,900
Air for complete combustion of 1 lb. dry at 60 deg. F. and 30 ins. mercury. Lbs. .	10·4	10·4	11·3	10·1	9·8	13·9
ditto in cu. ft. . .	136	136	148	132	128	182
Air for complete combustion of volatile matter in 1-lb. Lbs. .	3·9	1·7	0·8	0·5	Nil	13·9
ditto in cu. ft. . .	51·0	22·0	10·5	6·6	Nil	182
Ignition temperature in oxygen, deg. F. .	390	390	750	660	850–950	500 in oxygen 790 in air

characteristics of any fuel. The behaviour of the fuel in use is largely dependent on the kind and quantity of the volatile matter present. The volatile matter in British coals ranges from over 40 per cent. down to 6 per cent. In cokes the quantity may be less than 1 per cent., while the whole of a fuel oil is volatile matter.

If coal is heated to redness in the absence of air, the combustible part quickly decomposes, leaving a carbonaceous residue or " coke," and at the same time giving off a quantity of gases and vapours which will burn if ignited. The combustible part of this stuff which thus flies off the coke (the word *volatile* comes from a Latin word meaning " capable of flying ") is described as the volatile matter. Again, although the volatile matter is completely driven off only at a bright red heat—say 1750° F.—the bulk of it may be evolved below a red heat and, indeed, this portion is richest in hydrocarbons. These hydrocarbons decompose when heated so as to produce soot and tar. The volatile matter is the source of these " smoke producing " materials.

Whenever coal is thrown upon a red-hot fire, first of all the volatile matter, including the moisture, is driven off. As will be seen from Table I, this may amount to nearly half the weight of the coal, and the process takes place rapidly. Indeed, it is completed in a few minutes at a bright red heat. Moreover, this happens quite independently of the air supply, and whether the fuel is ignited or not. Whether a fire is to smoke or not, depends on the way this volatile matter is consumed, *i.e.*, on the design of the plant and the manner in which it is operated. Volatile matter can be consumed without smoke under certain conditions. To realise this it is only necessary to recall that fuel oil is all volatile matter, and yet, as is well known, lends itself under suitable conditions to smokeless combustion. The problem is, however, more difficult with a bituminous coal which contains both volatile and non-volatile combustible matter. Both have to be consumed together, but the conditions necessary for each are different.

It will be noticed that at least 10 lbs. of air are required for the complete combustion of 1 lb. of fuel. In practice more is necessary to secure smokeless combustion of bituminous coal. The volume of the air is at least 136 cu. ft. for a lump of coal about the size of a large fist. The large weight and volume of air for so small a piece of coal is very significant and too easily overlooked in practice because air is invisible. It is important in all applications of fuel—especially bituminous coals Moreover, the fact that the volatile matter alone may require over 50 cu. ft. per 1 lb. of coal usually necessitates the supply of the air in two parts: (*a*) primary air below the fuel bed, and (*b*) secondary air above the fuel bed. Similar circumstances apply in the burning of most combustibles, *e.g.*, wood, etc., and it is easy to see the importance of air supply in promoting or stifling fires.

Of this 10 lbs. of air, nearly 40 per cent. may be needed to burn the volatile matter which, as already stated, may rise from the top of the fuel bed of a bituminous coal before time and temperature conditions have allowed it to become ignited. It is possible to recognise three zones in the bed of a bituminous solid fuel burning in a grate. When fresh fuel is placed on the top of a glowing fuel bed, decomposition will proceed, allowing volatile matter to be driven off, to be burnt or not, depending on whether it is ignited or not. Below this top zone the carbonised residue or coke is consumed. On the grate bars air meets the glowing carbon which burns to CO_2 according to equation (1). It has been found that when the fuel bed is more than about 4 ins. thick the whole of the oxygen of the air will have been consumed and that the gases in the fuel bed consist of carbon dioxide diluted with nitrogen. If, however, the fuel bed is deeper the carbon dioxide so formed may be changed by reaction with the red-hot carbon to carbon monoxide as shown by equation (2). $C + CO_2 = 2CO$. This reduction of CO_2 to CO is never complete and the extent depends on the character of the carbon and the temperature. The gases in the fuel bed will now consist of hot CO_2, CO and N_2. These hot gases rise from the middle zone through the top layer of fresh fuel which is decomposed and the volatile matter set free is swept away in the gas stream.

It will be seen that there can be an infinite variety of combinations of these three zones, depending on the composition of the fuel, the form of the fuel bed, and the conditions of air supply. At one extreme, an open grate will tend to minimise the middle zone and by providing free access of air to the volatile matter rising from the top of the fuel bed, will promote completeness of combustion. At the other extreme a gas producer provides a deep fuel bed so as to encourage the reduction of carbon dioxide to carbon monoxide in the middle zone. Complete exclusion of air above the fuel bed ensures that all combustible gas—whether CO from the middle zone or volatile matter from the top layer—will pass on to be consumed as fuel where required.

Closed domestic stoves in construction and operation lie between these extremes, provision of air above the fuel bed being made to secure complete combustion. The construction and working of the furnace of a Lancashire steam boiler provides an excellent example of the existence of these zones of combustion of a bituminous coal. The "primary" air for reaction (1) is supplied below the grate while the "secondary" air to burn the volatile matter and carbon monoxide from the middle zone is supplied above the fuel bed.

It is appropriate to point out that combustion processes may be influenced by the amount of oxygen in the atmosphere. Just as animals may be asphyxiated by air which has been more or less deprived of oxygen, so will a combustion process be hindered or even stopped by a shortage of oxygen. This is exemplified by the extinction of a candle in a confined space where for any reason the atmosphere has been deprived of oxygen. On the other hand there are circumstances under which the atmosphere may be enriched in oxygen—*e.g.*, in the neighbourhood of plant where oxygen is manufactured. Combustion then may proceed with unusual and even dangerous violence. For this reason it is sometimes found necessary to prohibit smoking in the neighbourhood of oxygen plants.

The figures in the last line of Table I again draw attention to the importance of ignition temperatures. They differ widely and these differences determine the suitability of fuels for various purposes. The difference in ignition temperature, for instance, and not composition or calorific value, is the deciding factor in the usefulness of low or high temperature cokes for certain purposes. A high-temperature coke, made in gasworks or coke ovens, is more difficult to ignite and will more readily go out than another carbonised at lower temperatures. These differences in ignition temperature are also related to the tendency of some fuels to self-heating—a matter of great importance in connection with the problem of storing combustible material of which fuel is perhaps the most important example.

(*b*) *Wood as a Fuel.* In the matter of firefighting, wood is probably the most important fuel. The ignition, continuance and extinction of most normal fires depends to a very large extent on the properties of wood or charcoal. Charcoal is the product obtained when wood is carbonised or decomposed by heat in the absence of air. Wood is extensively used as a fuel in well-timbered countries. The behaviour of wood from different trees when burning varies, but there is little published information on the matter. Some years ago the Canadian Bureau of Mines noted the meagreness of accurate measurements and made some experiments on the burning of wood fuel in a closed domestic heating boiler. The fuels used were (*a*) hardwood (maple), and (*b*) softwood (pine). Each was tested both green and air-dried for two years. The measured properties of the samples tested are given in Table II below.

TABLE II

Composition and Properties of Wood

	HARDWOOD—MAPLE		SOFTWOOD—PINE	
	Air-dried. Seasoned 2 years	Green. Seasoned 3 months	Air-dried. Seasoned 2 years.	Green. Seasoned 5 weeks
Bulk density—weight per cu. ft. Lbs.	45·3	53·0	24·5	38·0
PROXIMATE ANALYSIS:				
Moisture	16·5	27·0	10·5	44·7
Ash	1·3	1·2	0·7	0·9
Volatile matter	66·5	50·0	73·8	42·8
Fixed carbon	15·7	12·8	15·0	11·6
ULTIMATE ANALYSIS				
Carbon	41·9	36·6	47·6	29·8
Hydrogen	6·9	7·4	6·8	8·3
Sulphur	0·3	0·3	trace	trace
Oxygen	49·4	54·7	44·8	60·8
Nitrogen	0·2	0·1	0·1	0·2
Ash	1·3	1·2	0·7	0·9
Calorific value gross B.Th.U. per lb.	7040	6410	8100	5000
Air for complete combustion of 1 lb. wood. Dry gas at 60 deg. F. 30 ins. mercury, lbs.	5·1	4·4	5·9	3·7
ditto in cu. ft.	67	58	77	48
Air for complete combustion of volatile matter in 1 lb. of wood, lbs.	3·3	3·0	4·6	2·3
ditto in cu. ft.	43	39	60	30
Ratio air consumed by volatile matter to total air consumption	0·64	0·67	0·78	0·63

It is interesting to compare the properties of these samples with those of the coals given in Table I. The coals have calorific values almost double those of the wood, a difference associated with the high content of oxygen and moisture in the wood. For general heating purposes woods are, therefore, low-grade fuels.

So far as concerns behaviour in burning, the proximate analysis is of first importance. Even dry wood has a moisture content higher than normal coals. As this moisture must be removed before ignition can begin, wood—especially green wood—exhibits a reluctance to ignite when first brought into contact with an incendiary source. The wide difference in moisture content of green and well-dried timber is significant in regard to fire risk. Heat in quantity is required to evaporate water from the timber and convert it into steam. This so-called "latent heat of vaporisation" is about 5½ times the quantity of heat required to heat the water from the freezing to the boiling point. This heat is absorbed without a corresponding rise in temperature and there is accordingly no ignition until this large quantity of water is removed. The advantage of drying firewood is well known.

After the temperature has risen somewhat above the boiling point of water—say to 340° F.—a marked decomposition of the wood begins with the evolution of large volumes of carbon dioxide, carbon monoxide and water vapour, due to the decomposition of the highly oxygenated matter of which wood is composed. In the region of 575° F. this decomposition becomes violent, and, owing to the liberation of heat, may cause self-heating with an actual rise of temperature. This phenomenon is due to the fact that cellulose is a major constituent of wood, and cellulose undergoes "exothermic" decomposition at about 575° F. When wood is heated in bulk in the manufacture of charcoal, this liberation of heat enables the later stages of carbonisation to proceed without external heating. It is possible that this spontaneous heating of wood plays some part in fire raising.

The large quantity and the kind of the volatile combustible matter also differentiate wood from other solid fuels. Taking the air required for combustion as a measure, the volatile matter, in the case of coals, is less than 40 per cent. of the total.

In the samples of wood quoted, 63 to 78 per cent. of the total air concerned was required by the volatile matter. As the volatile matter must travel in search of the air with which to burn, it means that woods must burn with long flames which are ideally fitted for promoting the spread of fires.

This combustion in long flames will be further encouraged by the high reactivity of the carbon in wood charcoal. Unlike coal, wood on carbonisation does not melt. The volatile matter is driven off at a low temperature, leaving the charcoal with the original porous cellular structure of the wood while the carbon itself is exceptionally reactive to oxygen, carbon dioxide and steam. Thus the ignition temperature of charcoal is below that of any coal or coke, so that it is easy to ignite and when alight must be cooled to a low temperature to ensure that no re-ignition can occur when extinguishing a fire.

Charcoal, as a result of this high reactivity, will readily react with carbon dioxide according to equation (2) $C + CO_2 = 2CO$ and with water according to equation (3) $C + H_2O = CO + H_2$, thus converting some of the fixed carbon into combustible gas, which is in effect a further increase in volatile matter and causes a greater length of flame.

The percentage of ash in wood is small but consists largely of alkali compounds which have the property of accelerating these reactions and so further promoting the conversion of carbon into combustible gas.

From these considerations it will be seen that the properties of wood—once the moisture is removed—all seem to conspire to promote the production of a long flaming fuel ready to burn and spread a fire quickly. It is the general experience that if a timber structure once gets alight, the fire burns and spreads with great rapidity.

The readiness with which dried wood will catch fire and develop a conflagration has led to many efforts to render the wood non-inflammable. These methods depend usually on impregnating or painting the wood with suitable materials of which there are many, such as borax, water-glass or sulphate, phosphates and other salts of ammonia. Generally the object is to provide a coating which prevents or hinders the access of air to the wood substance.

5. SPONTANEOUS IGNITION OF ORGANIC MATTER

The principal constituent of all organic matter—animal, vegetable, and also mineral fuel, is carbon, which seeks to combine chemically with the oxygen of the air. At normal air temperature this tendency may be, and usually is, slight. It is true that the union of oxygen with the organic matter gives rise to a liberation of heat which tends to warm the material, but the loss of heat to the surroundings may normally prevent any permanent rise of temperature. Should the temperature of the material be raised, the rate of combination with oxygen and consequent generation of heat will be increased. If this rise of temperature continues, a point may be reached at which the cooling cannot keep pace with the development of heat due to the chemical reaction for, in general, rise of temperature accelerates a chemical reaction more than the rate of cooling to the surroundings.

When the cooling becomes inadequate to dissipate the heat developed, the material will begin to self-heat and eventually burst into flame. The temperature at which this self-heating begins is called " the ignition temperature," but obviously it is not a fixed temperature. It will vary with the conditions at the time. Thus, if the loss of heat by cooling is reduced by any means such as the use of heat insulation, self-heating will start at a lower temperature. Anything which accelerates the rate of reaction will also reduce the temperature at which self-heating starts. The chemical structure of some materials is specially prone to oxidation, especially the presence of so-called " unsaturated bonds." An atom of carbon, for instance, has 4 bonds or links with which it can be linked with other elements ; it can, for instance, have 4 atoms of hydrogen and no more linked to it. Sometimes in carbon compounds 2 carbon atoms are found linked together although neither has all its four bonds attached to other atoms. Neither is fully saturated, and between the pair of carbon atoms there is an " unsaturated double " bond. Two links are vacant awaiting occupation by other atoms—especially oxygen. Where such a condition is found in a carbonaceous material the tendency to absorb oxygen is more marked. The absorption of oxygen and liberation of heat is intensified and the ignition temperature lowered. It is always possible for a combination of circumstances to lower the ignition point or temperature at which self-heating may start to normal air temperature, and then the material exhibits " spontaneous combustion."

Many vegetable oils contain unsaturated bonds and are well-known for their readiness to take up oxygen from the air, sometimes accompanied by a marked change in physical character as shown, for instance, by the " drying " oils. Where such oils are used in processing textile fibres, a product is obtained which is very liable to spontaneous combustion, for textile materials—especially wool—are among the best heat insulators. Oily textile material may readily absorb oxygen and generate heat which cannot readily escape.

In the case of new-mown hay the material may undergo oxidation under the influence of micro-organisms with the development of heat. If the heat is not dissipated rapidly enough self-heating may occur. The structure of a typical hay-stack does not favour the escape of heat and under certain conditions the temperature may rise until the stack catches fire.

Carbon itself can be prepared in a form which will absorb oxygen so readily that when exposed to cold air self-heating takes place until the carbon glows and catches fire. Most coals, under some conditions, will absorb oxygen from the air at normal temperatures so readily that self-heating will take place until the coal catches fire. Generally speaking the necessary conditions are that the bulk of the coal is large and the opportunities for dissipating the heat of oxidation are small. These conditions frequently occur in coal piles where fuel is placed in storage.

Self-heating may be initiated by local heating, as, for instance, by hot steam pipes near to coal bunkers on board ship. Many ship fires can be traced to local overheating. Conditions favourable to firing of coal are met in coal mines—especially those which are deep and hot, where freshly worked coal and finely divided coal are exposed to air. The coal surface is ready to absorb oxygen and the conditions underground are unfavourable to the dissipation of heat.

From these examples one can infer the general conditions conducive to spontaneous combustion, always bearing in mind that material which contains " unsaturated " bonds will be predisposed to absorb oxygen and initiate fires.

6. IGNITION TEMPERATURES

It will be noted that the words " ignition temperature " in this chapter are used with somewhat different meanings. In some cases, viz., the " spontaneous ignition temperatures " of an oil (p. 26), the ignition temperature of a gas (p. 27), or a solid fuel (p. 18), all relate to figures obtained when measurements are made with the fuel in three different pieces of apparatus, and the figures are not comparable. In all these examples heat has been supplied to the fuel to raise its temperature to ignition and so the use of the word spontaneous is rather unfortunate.

In defining ignition temperature provision must be made for ignition which takes place when no heat is deliberately supplied and a general definition has been given on p. 23 to include all cases. Spontaneous ignition and combustion then finds its place at the extreme where absorption of oxygen at air temperature with conservation of heat provides the conditions which sooner or later allow the combustible to catch fire. Some confusion of words is inevitable in view of the difference in fuels and observers who have used the terms with different meaning.

7. HYDROCARBONS

(a) Liquid Fuels. Compounds of carbon and hydrogen are to be found in practically all useful fuels and in animal and vegetable matter. Compounds of carbon and hydrogen alone are called "hydrocarbons" and occur as gases, liquids and solids at air temperature. The commonest class is the "paraffin" hydrocarbons, viz. methane (marsh gas, or the firedamp of the coal mines), butane (prominent constituent of "calorgas"), the components of petrol, kerosene or lamp oil, gas oil, and petroleum lubricating and fuel oils. Another important class, the "aromatic" hydrocarbons, includes the components of the spirits and oils obtained from coal tar, viz. benzene, naphtha, naphthalene, creosote, pitch, etc. On combustion with sufficient oxygen, all hydrocarbons yield carbon dioxide and water vapour. Taking the burning of benzene as an example, this is illustrated by equation (8).

	C_6H_6	$+ 7\frac{1}{2}O_2$	$= 6CO_2$	$+ 3H_2O$ + 88,530 B.Th.U. for 78 ozs. benzene . . . . (8)
Weight in ozs.	$(72 + 6)$	$+ (7{\cdot}5 \times 32)$	$= 6\,(12 + 32)$	$+ 3\,(2 + 16)$
Vol. in cu. ft. at N.T.P.	22·4	7·5 × 22·4	6 × 22·4	3 × 22·4

Heat of reaction 88,530 B.Th.U. liberated per 78 oz. benzene, or 18,160 B.Th.U. per 1 lb. of benzene.

The advantage of the use of chemical equations is now apparent, for the behaviour of matter can be set down in a convenient form which takes account of the composition—whether it be of elements or compounds and however complicated the molecule may be. The heating value of 1 lb. of carbon is 14,450 B.Th.U. but that of 1 lb. benzene is 18,160 B.Th.U. The high calorific value is due to the large proportion of hydrogen in benzene. The proportion is still higher in the paraffin hydrocarbons and accordingly they have still higher calorific values, as can be gathered by inspection of the figures given in Table III. In the first four columns are given certain properties of typical petroleum oils—all paraffin hydrocarbons. The last two columns give these properties for motor benzole and creosote, both of which contain compounds of aromatic hydrocarbons.

It will be noticed that the composition of the paraffin hydrocarbons varies within rather narrow limits, and the same is true of their calorific values. The oils differ in density or specific gravity.

The fire risk of a liquid fuel is mainly dependent on its volatility

TABLE III

Liquid Fuels

Composition	Paraffin Hydrocarbons				Aromatic Hydrocarbons	
	Petrol	Kerosene	Diesel oil	Heavy fuel oil	Motor benzole	Creosote
Carbon	85·3	86·3	86·3	86·1	91·6	89·0
Hydrogen	14·7	13·6	12·8	11·8	8·0	7·0
Sulphur	·02	0·1	0·9	2·1	0·3	0·8
Specific gravity	0·74	0·79	0·87	0·95	0·878	1·07
Calorific value gross B.Th.U. per lb.	20,120	20,050	19,780	18,900	18,100	16,700
Flash point, deg F.	0 to 33	102	168	230	12	over 150
Spontaneous ignition temperature in oxygen deg. F.	540	500	520	500	750	840 to 930

or tendency to vaporise and so develop an explosive mixture with air. The "flash point" is usually taken as a guide to volatility. The forms of apparatus used for measuring flash-point differ, but are all based on the same principle. The sample is heated in a cup—open or covered—and at intervals a flame is applied as the temperature rises. Eventually a temperature is reached at which a blue flash passes over the surface of the oil and the corresponding temperature is taken as the flash point. In order that the flash may occur, it is necessary that an explosive mixture of oil vapour and air is produced over the oil. It will be seen that with petrol and benzole this may happen if the fuel has a temperature below the freezing point of water, whereas a heavy fuel oil needs a temperature above the boiling point of water. Flash points are usually taken as a measure of safety in storage, handling and transport.

The ease of ignition when oils are heated in contact with oxygen is another important characteristic, especially in engines of the Diesel type. The measurement of the so-called spontaneous ignition temperature is one test used for the purpose. A hollow block of metal is heated, while a stream of oxygen is passed through the chamber. When a drop of oil is allowed to fall into the chamber it may or may not burst into flame and the lowest temperature at which this happens is taken as the spontaneous ignition temperature. It will be noticed that the figures for tar oils are much higher than those of petroleum constituents.

(b) Gaseous Fuels. All important fuel gases contain hydrogen or compounds of carbon, usually with hydrogen, and sometimes diluted with incombustible gases such as nitrogen and carbon dioxide. Methane (CH_4), found in nature and known to coalminers as firedamp, is the principal constituent of the natural gas which is evolved by petroleum oil wells.

The composition and some important properties of fuel gases are given in Table IV. Most manufactured gases contain as essential components, hydrogen, carbon monoxide and methane, the properties of which are given in columns 1, 2 and 3. Typical figures for manufactured gases are given in columns 6, 7 and 8. The main component of " bottled gas " or calorgas is butane, and pure acetylene is supplied in dissolved form in cylinders for cutting and welding. Their properties are given in columns 4 and 5.

TABLE IV

Gaseous Fuels

Composition	SIMPLE COMPOUNDS					MANUFACTURED FUELS		
	Hydrogen (1)	Carbon monoxide (2)	Methane (3)	Butane (4)	Acetylene (5)	Coal gas (6)	Water gas (7)	Producer gas (8)
Hydrogen	—	—	—	—	-	49·4	49·0	11·0
Carbon monoxide	—	—	—	—	—	18·0	41·0	29·0
Methane	—	—	—	—	—	22·0	0·8	0·5
Oxygen	—	—	—	—	—	0·4	—	—
Carbon dioxide	—	—	—	—	—	4·0	4·7	5·0
Nitrogen	—	—	—	—	—	6·2	4·5	54·5
Calorific value B.Th.U. per cu. ft. at 60 deg. F. 30 ins. mercury moist, gross	320	318	995	3240	1460	475	295	132
Limits of inflammability. (Percentage of gas in mixture with air) :								
Lower	4·1	12·5	5·3	1·9	2·3	5	6–9	—
Upper	74	72	15	8·5	—	31	55–70	
Ignition temperature, deg. F.	1070	1180	1040	880	600	—	—	—

The flame of a gaseous fuel may be obtained in several ways:

(*a*) The gas may emerge from an opening, diffuse into the surrounding air with which it burns.

(*b*) The gas, previously mixed, with part of the air for combustion—so-called " primary air "—may, after partial combustion, emerge from an opening and complete the combustion with the outside " secondary air," and

(*c*) The gas and air may be led separately into a chamber where they ignite and burn—the system commonly employed in industrial furnaces. In connection with fire hazards the second method of flame production is most important because explosions are not produced until both gas and air have mixed.

Before a gas can burn it must meet and mix with sufficient air to enable combustion to be propagated through the mixture. There are limits of gas content between which inflammability is possible.

The motorist is familiar with the requirement that a petrol-air mixture must be rich enough, but not too rich. The actual limiting percentages of gas in the mixture vary according to conditions of measurement, *e.g.*, if the flame rises upwards through the mixture, the lower limit is smaller than if the flame must travel downwards against gravity. In general, when considering safety, it is the lowest possible limit of inflammability which is of practical importance. It will be noticed that the limits are not necessarily governed by the calorific value of the gas. The lower limit for carbon monoxide is 12·5 per cent., *i.e.*, three times that of hydrogen, although both have virtually the same calorific value.

Nevertheless, it is generally true that vapours of the heavy complex molecules—*e.g.*, vapours of benzene and petrol—have the smallest lower limits. Thus mixtures of air with benzene (C_6H_6), petrol or butane (C_4H_{10}) which contain less than 2 per cent. of the vapour will yield explosive mixtures—a matter of great practical importance when considering safety precautions. A mixture containing about 5 per cent. of methane with 95 per cent. of air is on the lower limit of inflammability of mine air. This is a figure of great importance to the coal-mining industry, and safety demands the regular analysis of mine atmosphere and efficient ventilation to ensure that this figure is not overstepped. Safety lamps must be used, which are incapable of igniting a dangerous mixture.

When a mixture of combustible gas and air is heated, a temperature is reached at which the mixture will burst into flame. The temperature necessary for ignition depends on the gas in question and also on the conditions. In one method for measuring ignition temperatures, the gas and air are preheated separately to the same temperature before they are brought together to see if they burst into flame. The lowest temperature at which ignition occurs is taken as the ignition temperature. A set of figures so measured is given in Table IV.

After the gas-air mixture is ignited, the flame may travel through the whole mixture causing rapid generation of heat, increase in volume of gas and rise in temperature, and consequent rise in pressure with the well-known consequence of an explosion.

In this connection it should be recalled that finely divided solid combustible matter behaves like a combustible gas. Dispersed in air and subjected to local heating, an explosion may be initiated. The volumes of mixture in industrial conditions may be large and consequently if such an explosion is produced, the consequences are disastrous. The best known example is furnished by the dust explosions in coal mines. Similar results may follow the ignition of a cloud of dust in many factories when dusty processes are operated, *e.g.*, milling of flour and, indeed, any which depend on the fine pulverisation of combustible solids.

8. THE STRUCTURE OF FLAMES

When a gas burns the volume of air necessary for complete combustion is always greater than the volume of the gas itself and almost proportional to the calorific value of the gas. Thus hydrogen requires about 2½ volumes of air for 1 volume of gas, a coal gas of the analysis given in Table IV requires over 4 volumes, while benzene (equation 8) requires about 37 volumes of air per volume of benzene vapour. The volume of air relative to the volume of fuel is always noticeably great—especially when solid and liquid fuels are burning. Where useful combustion processes are in question these circumstances always create difficulties. The larger the scale, the greater the difficulty of obtaining completion of admixture of air, and, therefore, of combustion. Incomplete aeration of hydrocarbon flames reveals itself in luminosity and, in extreme cases, in the production of smoky flames, as exemplified by the behaviour of an oil lamp.

Some guidance can be obtained by considering the structure of a coal-gas flame obtained with a Bunsen burner. Suppose we light the burner and close the air ports. Ignoring the flickering caused by air disturbances, it will be found that the flame really consists of a hollow shell of flame filled with a cold mass of gas. This is unburnt gas rising upwards and outwards in search of the air it needs for combustion. The size and shape of the flame is dictated by the distance and direction of travel necessary to reach the requisite air. The upper region of this hollow shell is coloured yellow because some of the hydrocarbons are decomposed with liberation of fine particles of solid carbon which glow at the high temperature of the hot shell of flame.

If the air port of the burner is now gradually opened it will be seen that the flame may at first be slightly enlarged because of the increased volume of mixed gas, but it will soon shorten and lose the yellow colour. The added air causes oxidation of the carbon, while the presence of free air within the outer shell makes it unnecessary for the gas to travel so far in search of air. There will also appear, first of all near the base of the flame, what looks like a lining to the outer shell, bluish in colour, where the air is sufficient to cause the separation of a second flame of partial combustion. Further increase of air supply causes this inner flame to shorten, grow more deeply blue in colour and then acquire a well-defined conical form. Indeed, it is normally referred to as the " inner cone " and the outer shell as the " outer cone " of the Bunsen flame. The inner cone is really a zone of combustion of a gas-air mixture, a flame travelling against the stream passing from the Bunsen. It is maintained in position by this flow, and, indeed, if the rate of outflow becomes inadequate the flame will " strike back " through the gas mixture by an explosive movement on a very small scale. When this striking back occurs, the outer cone or shell is extinguished and the gas mixture leaves the burner incompletely burnt.

The construction of an ordinary Bunsen burner is such that only about one-half of the air required for the complete combustion of the gas can enter the air ports. In consequence, the gases discharged by a burner which has struck back are only half consumed and are rich in carbon monoxide and free hydrogen. This is equally true of the gases within a normal Bunsen flame, *i.e.*, in the space between the inner and outer cones.

What happens in these small flames gives some guide to the conditions in large flames. The difficulty of getting air into contact with combustible matter forces the volatile combustible matter to go far in search of air and is responsible for the long flames of a conflagration. In the absence of oxygen within the flame, the hydrocarbons are heated to decomposition, giving rise to tarry and sooty decomposition products which are carried away by the flame—in other words, to the black smoke characteristic of the flames of carbonaceous material.

Some metals burn with the production of white smoke—*e.g.*, zinc and magnesium. These metals boil at a relatively low temperature—zinc at 1706° F. and magnesium at 2012° F., so that the flame is one of metal dispersed in gaseous state. The product of combustion is formed also in a dispersed state as a fine cloud of magnesium oxide. Unless burning material or its product is in the gaseous state, no long flame is produced. It is a matter of importance to fire risk whether a combustion process leads to a long flame or not. Solid reactions, such as the thermite reactions accompanied by the evolution of heat without the formation of much gas, produce little or no flame.

9. BACK DRAUGHT

Where combustion is taking place on a larger scale, there is always danger ranging in degree of gravity from the development of explosive mixtures of gas and air. Even if the explosion is not violent it may suffice to drive a flame back and burn persons nearby. A good example is furnished in steam boiler practice. When a Lancashire boiler is shut down overnight or at meal times, the fuel bed may be covered with raw fuel. Under the influence of heat, gas will be given off and drawn by the slight chimney draught into the flues. When the time comes to start up the boiler, if the damper is incautiously opened there is danger of air explosion in the flue system with consequences which may vary from minor burns to the fireman to a very destructive explosion. In such cases, there will have accumulated gas-air mixtures which, in composition, approach the appropriate limit of inflammability. The opening of the damper allows the inrush of air, bringing the mixtures within the range of inflammability and only a flame or spark may be necessary to cause ignition. It should be remembered that great damage can be caused by the inflammation of weak mixtures when the bulk is large.

Analogous phenomena can occur in burning buildings, if circumstances allow pockets of mixtures of air and unignited combustible gas to accumulate. Wood, for instance, decomposes to give gaseous products at quite low temperatures. Some materials such as celluloid are even more unstable. Coal gas may escape. Hydrocarbon oils especially, such as petrol or naphtha, may readily give rise to rich mixtures of air and vapour. An inrush of fresh air from any source or cause, will bring the mixture into a dangerous condition, giving rise in the mildest cases to a return of flame against those near the fire. The hot gases in a burning building, being lighter than air, provide inward draught just like the chimney of the boiler and only await the opening of a door or window to draw in air, sufficient to produce an explosive mixture.

PART I CHAPTER 2

EXTINGUISHING FIRE

IN the previous chapter, the chemical reactions which produce fire were described from the scientific viewpoint. It is now proposed to relate this knowledge to the subject of fire extinction, and to refer to the various methods at present employed.

It has been shown that three factors are essential to combustion, namely :

(*a*) The presence of a fuel, or combustible substance.

(*b*) The presence of oxygen (usually as air) or other supporter of combustion.

(*c*) The attainment and maintenance of a certain minimum temperature.

Fire extinction, in principle, consists in the limitation of one or more of these factors, and methods of fire extinction may therefore be conveniently classified under the following headings :—

1. Starvation, or the limitation of fuel.
2. Smothering, or the limitation of oxygen.
3. Cooling, or the limitation of temperature.

In practice, specific methods of fire extinction often embody more than one of these principles, but it will be convenient to consider them according to the main principle involved.

I. STARVATION

This method is applied in three ways :—

(*a*) By removing combustible material from the neighbourhood of the fire ; Examples of this are, the drainage of burning oil tanks ; the working out of cargo at a ship fire ; the demolition of buildings to create a fire stop ; the cutting of trenches in peat, heath and forest fires ; counter-burning in forest fires, etc.

(*b*) By removing the fire from the neighbourhood of combustible material as, for instance, pulling apart a burning haystack or a thatched roof.

(*c*) By subdividing the burning material, when the smaller fires produced may be left to burn out or to be extinguished easily by other means. A typical example is the emulsification of the surface of burning oil, whilst the beating of a heath fire owes much of its effectiveness to this.

2. SMOTHERING

(*a*) *By Reducing the Oxygen Content.* If the oxygen content of the atmosphere in the immediate neighbourhood of burning material can be sufficiently reduced, combustion will cease. The general procedure in methods of this type is to prevent or impede the access of fresh air to the seat of the fire, and allow the combustion to reduce the oxygen content in the confined atmosphere until it extinguishes itself. This principle is, of course, ineffective where, as in the case of thermite, the burning material contains in itself in a chemically combined from the oxygen it requires for combustion.

The principle of smothering is employed on the small scale in snuffing a candle, and, on the large scale, in capping a burning oil well, two processes which are precisely analogous. The battening down of a ship's hold when a fire breaks out below decks will often hold the flames in check until port is reached.

Small fires, such as those involving a person's clothing, can be smothered with a rug, blanket, etc., while the use of sand or earth on small fires is a further instance of the same principle.

An important practical application of the smothering method is the use of foam. This forms over the burning material a viscous coating which, in so far as it is complete, limits the supply of air.

Another class of smothering agent may be described as temporary in its blanketing effect. Thus the vigorous discharge of an inert gas or vapour in the immediate vicinity of the fire may so reduce the oxygen content of the atmosphere for the time being that combustion cannot be maintained. Carbon dioxide and methyl bromide vapour are familiar examples of this. With fires of any magnitude, however, the convection currents set up are sufficiently powerful to dissipate the inert atmosphere formed by the application of a gas blanket before the extinguishing action can take effect. The application of certain of these media in the form of a liquid which is then vaporised by the fire, thus forming the required inert atmosphere, is more likely to prove effective, particularly as a cooling effect is also operative. See section on Cooling.

(b) By Excess of Oxygen. The methods of fire extinction so far mentioned in the present section depend on *reducing* the oxygen content of the supporting atmosphere until the *upper limit of combustion* is exceeded. It is possible in certain cases to employ the reverse process, that is to pass so much air across the burning material that the *lower limit of combustion* is traversed and burning ceases through a local deficiency of fuel (or excess of oxygen). It is well known that a certain draught is essential to rapid combustion, but when the most suitable rate of air supply is exceeded combustion is impeded, and, in the limit, totally inhibited. Thus, while a gentle application of the bellows to a coal fire will facilitate burning, the application of the same draught to a candle will extinguish it. It is by the application of this principle that oil well fires are extinguished by the blast from exploding dynamite. Such techniques do, of course, also involve to a considerable extent the cooling principle treated in the next section.

3. COOLING

If the rate at which heat is generated by combustion is less than the rate at which it is dissipated through various agencies, the combustion cannot persist. In applying this principle to fire extinction the first step is to accelerate the speed with which heat is removed from the fire, thus reducing the temperature of the burning mass and as a consequence the rate at which heat is produced.

In due course the rate at which heat is lost from the fire exceeds the rate of heat production and the fire dies away.

This method of fire extinction is the one most commonly employed, forming as it does the basis of the application of water and other liquids to burning materials. The extinguishing medium operates by absorbing heat from the fire, as a consequence of which it may undergo one or more of the following changes :—

(*a*) Its temperature is raised ;
(*b*) It is converted to the vapour state ;
(*c*) It is decomposed ;
(*d*) It reacts chemically with the burning material.

It is clearly desirable that the quantity of heat required to produce any or all of these changes in a given quantity of an extinguishing medium should be as high as possible. That is to say, referring specifically to the above headings, that the following values should be as high as possible :—

(i) The amount of heat absorbed for any given increase in temperature (the thermal capacity).

(ii) The amount of heat required to vaporise a unit weight of the extinguishing medium (the latent heat of vaporisation).

(iii) The amount of heat required to cause the decomposition of a unit weight of the extinguishing medium (the heat of decomposition).

(iv) The amount of heat required to cause a unit weight of the extinguishing medium to react chemically with the burning material (the heat of reaction).

The action of water depends predominantly on (i) and (ii), the latter being by far the more important. Thus it takes about six times as much heat to convert a certain weight of water at its boiling point into steam as is required to raise the temperature of the same amount of water from the usual atmospheric value to its boiling point. In the interests of efficiency, then, it is clearly desirable that water should be applied to a fire in the liquid condition and in such a way that as much as possible is converted to steam. The smothering effect of the steam produced at the seat of fire is thought to play a part in assisting in the extinguishing process. In all firefighting operations where water is in use it should be the aim to ensure that the proportion of water which escapes from the building in liquid form to that which is applied should be as low as possible. When the heat of a fire is considerable, as in its early stages, the steam formed will not be visible, but as the temperature falls the steam will condense above the fire. This is widely recognised by experienced fire officers as a sign that a fire is being brought under control.

On a basis of thermal capacity and latent heat of vaporisation, water is an excellent fire extinguisher, since both figures are high. This fact, combined with its availability in large quantity, make it by far the most useful fire extinguisher for general purposes. The principle of decomposition probably has little application, as water is fairly stable except at very high temperatures. Certain substances (*e.g.*, carbonates) absorb heat in this way, but the principle is not of much practical consequence at present. Nor is water usually effective in absorbing much heat by reacting with the burning substance. Some extinguishing media may in certain circumstances prove dangerous in this connection, their reaction with the burning substance resulting in the *evolution* rather than the absorption of heat. Moreover, the reaction may result in the production of a substance which is itself combustible, thus adding fuel to the fire. The action of water on burning magnesium exemplifies both these effects, since it reacts with the metal exothermically (*i.e.*, producing heat) with the formation of hydrogen, which is readily ignited. In the case of other media the reaction products may be undesirable in other senses, as in the case of carbon tetrachloride, which under certain conditions may evolve phosgene, a highly poisonous gas.

PART I CHAPTER 3

METHODS USED BY THE FIRE SERVICE

THE principles underlying the methods employed in extinguishing fire have been dealt with in the two previous chapters. Here it is proposed to show very briefly how each of these principles requires the use of specialised Fire Service equipment, which will be described in detail in subsequent chapters.

The primary aim of the Fire Service is first to save life, then to extinguish fire. Special types of ladders, such as escapes, which can be rapidly slipped from the appliance and moved into position have been in use for many years, as have hook ladders designed for use where an escape or other type of ladder cannot be employed.

Rescue work requires the use of lines of proved strength and has led to the development of special types together with such ancillary equipment as slings and hooks.

Since the most generally applicable method of extinguishing fires employed by the Fire Service is by cooling, water is extensively used.

To prove effective this water must be projected on to the heart of the fire. If small quantities only are required the necessary force may be obtained by chemical means, as in the soda acid extinguisher, by the release of stored-up mechanical energy as in the compressed gas capsule type of extinguisher, or by manual work such as working the handle of a stirrup pump up and down.

Alternatively, where the fire is too large to handle by these means and greater quantities of water are necessary for its extinction, mechanical methods of imparting the necessary energy to the water must be employed. Pumps may be driven by internal combustion engines or by steam or electricity. A few "steamers" are still in use by the Service; electricity as motive power is restricted to stationary units employed in fixed firefighting installations. The vast majority of the pumps in use are driven by an internal combustion engine.

To deliver the water where it is required, hose must be used, and numerous fittings of different types are necessary to couple up the hose and to deliver the desired quantity of water on to the fire and wherever the fire may be, often under difficult conditions of access. The form most suitable is in jets of various sizes or in the form of spray, etc. This involves the use of an extensive range of branches, nozzles, adaptors, couplings and other similar gear.

Fire fighters must be enabled to approach the fire irrespective of its location. This may necessitate the provision of ladders, escapes and a miscellaneous assortment of gear for breaking in and cutting away. Thus the necessity for obtaining access to high buildings and directing jets of water on to the fire from above or to protect the roofs of property has led to the development of such appliances as the turntable ladder. Various forms of padlock removers, door breakers, axes, saws, crowbars, etc., form part of the equipment of every well-appointed fire appliance.

Poisonous atmospheres which hinder approach to the fire or make search impossible have led to the development of breathing apparatus which will enable the wearer to enter and work in safety in an unbreathable atmosphere. Operations at fires at night, except under war conditions, require that adequate illumination shall be available, and the Fire Service therefore provides lights for all purposes.

Special types of fires such as those involving liquids lighter than water cannot be dealt with by means of water jets, and specialised equipment such as foam-making branches and certain types of emulsifying equipment are used in fixed installations and spray nozzles on appliances. Chemicals stored in cylinders under pressure or which can be ejected by the release of pressure such as CO_2, methyl bromide and carbon-tetrachloride are widely used. The provision of rubber gloves and shorting gear for overhead wiring is a direct outcome of the need for protection against electrical dangers. Fires in ships or in dockside premises require special treatment and fire boats with their particularised equipment, such as rocket pistols for getting lines ashore, have been developed.

The provision of adequate water supplies for firefighting, although originally the function of the water authorities, and sometimes a problem even in peace, has been rendered infinitely more difficult by war. The responsibility for providing supplementary water has been thrown on the Fire Service, and many types of supply have been developed. Access to streams, rivers and lakes has been improved so that appliances may set in, and methods have been developed such as mobile dams and water relaying for using these supplies to make good deficiencies at a distance.

In addition to the many classes already listed, much other equipment, particularly that known under the general heading of " small gear," has been developed where its use has been found of value.

In general, however, over-specialisation is to be deprecated. The development of one particular item of equipment capable of carrying out one operation only, however efficiently, involves the stowing of much material which may be used but rarely. Soundly designed, well cared-for apparatus capable of a wide diversity of uses will inevitably prove more suitable and, over a period of time, more efficient.

PART I CHAPTER 4

HOSE

ITS CONSTRUCTION, CARE AND MAINTENANCE

IN this chapter it is proposed to describe the various types of hose, both delivery and suction, which are in general use in the Service.

Hose may be divided into two main groups :—

Delivery hose, used where the water passing through it is at pressures above that of the atmosphere.

Suction hose, used where the water passing through it may be under pressures either below or above that of the atmosphere.

This first group may be subdivided into :—

1. Woven types of hose—flax, cotton, etc.
2. Composite types, part fabric and part rubber, such as duck-covered rubber hose and first-aid tubing.
3. Rubber hose or tubing used for washing down and other similar uses.

The second group includes the various types of armoured hose, constructed to withstand external pressure.

DELIVERY HOSE

1. WOVEN TYPES

(*a*) *Materials Used.* The first hose used was made of leather. It was made only in short lengths owing to its great weight, and this, added to the fact that it had to be periodically greased to keep it pliable, made it very difficult to handle. The hose was riveted throughout its length (Fig. 1) and replacing a rivet in the centre of a length was a major operation. The rivet was first inserted, then a mandrel was passed into the hose to act as a seating for the rivet while the washer was put on and clinched. Leather hose is occasionally employed in modified form for "flexible" branches used when working from a ladder.

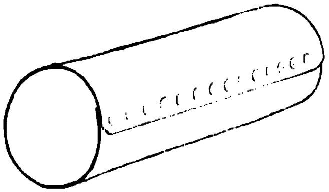

Fig. 1. Sketch showing a piece of old leather hose.

Following leather, came flax (woven) hose, manufactured first in Scotland in 1850, the quality of the hose being steadily improved with the development of the necessary weaving plant.

Unlined hose can be made with varying degrees of success from ramie, cotton, hemp, specially processed jute, and some other less well-known vegetable fibres.

(i) ***Hemp.*** Hemp as usually available makes a very stiff hose, and one which is subject to rapid deterioration in use. It has been found that a hemp weft with a flax warp makes a hose of fair quality, but only when soft hemp of the best quality is used.

(ii) *Cotton.* Cotton has only been used experimentally for unlined hose, and the experiments have not been successful. It is extensively used for rubber-lined hose and the major quantity of this type of hose now has a cotton jacket.

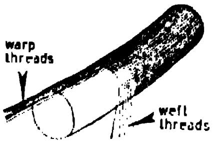

Fig. 2. Sketch showing "warp" and "weft" threads.

(iii) *Ramie.* This fibre, prepared from raw material derived from China, East Africa, Egypt or Assam, makes a first-class unlined hose, but only when the fibre has been degummed, and, if necessary, further processed to such a degree of purity that it may be readily spun. Ramie is probably the strongest vegetable fibre known, but in present conditions it is very difficult to obtain; its cost is unduly high for this reason, and also the processing is costly owing to the quantity of gum and other impurities to be removed.

Due to the great inherent strength of the fibre, a ramie jacket has been used during the last 60 years where great strength has been required, but the fibre used for these special orders was incompletely degummed and would not have been satisfactory in an unlined hose. The strength of ramie is due to three reasons: (*a*) the great inherent strength of the ultimate fibre strand; (*b*) the adhesive strength of the gum content of the plant, and (*c*) the gums do not readily degenerate in strength. They possess certain preservative qualities which are essential for some needs. Ramie hose is used to some extent on the Continent of Europe. More recently good quality ramie unlined hose has been constructed in the course of experimental work carried out under the direction of the Home Office.

(iv) *Jute.* This is a coarse fibre which is not used for the manufacture of hose, though new methods of processing the fibre indicate that unlined hose of usable quality could be made if necessary.

(v) *Synthetic fibre.* A considerable amount of work has been done in making unlined hose from rayon fibres. None of the samples of hose so far obtained has proved of usable quality, but some few of the experiments have been sufficiently promising to justify further development work and it is possible that a composite hose made from special rayon fibre in conjunction with flax or hemp and cotton will ultimately be found capable of extended use.

(vi) *Flax.* This has been the standard fibre used in the manufacture of unlined fire hose for many years past.

Prior to the second world war the great bulk of flax employed in this country was imported from Europe. Home-grown supplies have now replaced the bulk of these imports.

(*b*) *Construction.* The fabric of canvas hose consists of two sets of yarns running at right angles to each other (Fig. 2), those running lengthwise being called the "warp threads" and those running crosswise the "weft threads." Whilst each warp yarn almost invariably consists of a single thread only, the weft yarn may vary from a single up to as many as twenty or occasionally more threads.

The warp or longitudinal threads in hose are those that give it durability to resist wear and tear, while the weft or crosswise threads resist the tendency of water pressure to burst the hose; this explains why they are thicker than the warp threads.

Hose is woven in two ways, *i.e.*, "plain" and "twill." In plain woven hose (Fig. 3, *left*) the warp threads are woven under one and over one, throughout the fabric. This type is generally used for unlined hose. In "twill" woven (Fig. 3, *right*), the warp threads are woven on the principle of over two and under one; such fabric is indisputably stronger and more pliable, but less watertight than plain woven hose; it is usually manufactured, therefore, for lined hose. Whilst in a destruction by pressure test on "plain" woven hose it is almost invariably the weft that breaks, in circular twill-woven hose there have been many instances of a warp and weft break occurring in the same short length. In short lengths of new hose tested in a confined trough of 27 in. radius the warp always breaks at about 50 per cent. of the average bursting point for the same hose when tested straight.

After hose is woven it is sometimes given a zinc-chloride treatment known as "burnettising," the object of this being to reduce susceptibility to mildew and to add to its softness and flexibility. There is a wide divergence of opinion as to the value of this treatment.

(i) *Unlined Hose.* Unlined hose is woven on either flat or circular looms. The former are well established and produce a satisfactory standard article, and the latter, whilst not copies of the original loom, have been brought to a great pitch of perfection in America as well as in this country. The output of the circular loom is larger, and it cannot be disputed that the circular loom can weave a hose capable of withstanding much greater pressures, but there are arguments in favour of each type, and both types have produced fire hose which is in daily use. Other factors being equal, hose woven on the flat is weaker generally, and in particular at the selvedges or longitudinal creases.

The main essential in selecting unlined hose is to ensure that it has sufficient pressure-resisting strength to withstand the maximum pressure to which it is likely to be subjected in service, plus an allowance for wear and a safety margin. The next essential is to see that the canvas is woven reasonably tight, that is, it should have only small leakage when under pressure; it is possible for manufacturers to produce a hose that is practically watertight, but this has the disadvantage that it is almost inflexible, is easily damaged by chafing and tends to break when kinked.

A well-designed unlined hose will leak at first, but as the fabric becomes saturated with water the threads of the fabric swell and render the hose nearly watertight. This swelling is to a great extent retained after use, so that when the hose has been used and dried several times it leaks much less than at the first time of using.

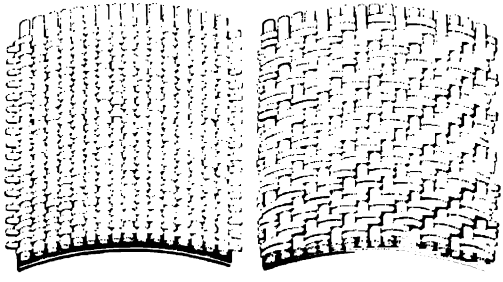

Fig. 3. Left: "plain" weave. Right: "twill" weave.

(ii) *Rubber-lined Hose.* As leakage from even the best of unlined hose is a very undesirable matter, rubber-lined hose is becoming more extensively used

The process generally used for lining hose with rubber is briefly as follows :—

First a good quality rubber tube of the correct size is made, and is then partially vulcanised to harden it and to prevent distortion while it is being inserted into the hose. After this it is wrapped with a thin sheet of black rubber termed "backing", which is easily soluble when heated. The flax or cotton hose is laid out at full length in a specially constructed trough and is held in position while the prepared rubber lining with its "backing" is drawn into it by means of a line. When the lining is in position one end of the hose is connected to a steam pipe, the other end being blanked off except for a small drain cock. The hose is then put under steam pressure, the heat of which softens the black soluble rubber and causes the rubber lining proper to become fused to the hose, also completing the vulcanising. The approximate steam pressures used are 25 lbs. per sq. in. for the first 30 minutes, after which it is increased to 50 lbs. per sq. in., which pressure is maintained for periods up to one hour. These pressures and times are varied according to the accelerating agent that may be used in the soluble rubber.

An alternative method of lining hose with rubber has recently been developed, but is not as yet widely used in this country. This method is briefly as follows :—

Hose is treated in lengths of about 100 ft. at a time. The length to be lined is tightly stretched in a special chamber between screw grips which control the tension of the hose. Rotating wires, to which are attached rubber brushes, are passed through the hose and over rollers at each end so that the brushes can be drawn through the hose in either direction. A sufficient quantity of rubber solution is then blown into the hose by compressed air and distributed evenly throughout the length by the rotating brushes, which also draw out any excess solution. This process is repeated until a lining of sufficient thickness is achieved. About five hours is taken by this method to deposit a lining of from $\frac{3}{50}$ in. to $\frac{4}{50}$ in. thick. Vulcanisation is accomplished by blowing hot air (at about 300° F.) through the hose for a period of approximately forty minutes.

The cost of lined hose—from 75 per cent. to 100 per cent. higher than that of unlined hose—is a serious item in the cost of equipment.

(iii) *Cotton-jacketted Hose.* Owing to limitations in the supply of flax, cotton-jacketted lined hose has been extensively adopted. The chief disadvantages of cotton-jacketted as against unlined hose are that it is heavier, it occupies more space, it does not handle so readily, and the initial cost is greater. The advantages are that it does not allow loss by percolation, it reduces water damage, it is hydraulically more efficient and it is very much better wearing.

In America cotton-jacketted hose, which is almost exclusively used (although it is replaced to some extent by flax unlined hose for forest service) is usually double jacketted. The purpose of additional jackets is twofold.

(i) To protect the hose proper against damage.

(ii) To strengthen resistance to internal pressure and tensile strain.

For this purpose the outer jacket or jackets should be stronger than the inner jacket. Additional jackets add to the weight and bulk and reduce flexibility, and, when the inner hose is damaged, repair is made correspondingly more difficult. The single jacketted hose which has been issued in large quantities to the Fire Service in this country is manufactured in the manner already described.

(c) *Characteristics of Hose.* (i) *Percolation Losses in Unlined Hose.* Tests carried out on short lengths of 1¾-in. dia. unlined hose showed considerable variation as between two samples, but the figures given in Table I might be accepted as giving a guide to losses in gallons per minute per 100 feet in hose of this size after it has been in use for approximately ½ hour.

TABLE I

Pressure in lbs. per sq. inch.	Loss in gallons per minute per 100 feet.
25	·103
50	·155
75	·206
100	·469

A similar series of tests carried out on a number of samples of 2¾-in. diameter unlined hose again showed that very considerable variations occur. An average taken for a number of specimens tested showed, however, that the rate of percolation tended to decrease with the length of time and to increase with rise in pressure. After it has been in use for approximately ½ hour, 2¾-in. diameter unlined hose should not lose by percolation more than 1⅞ gallons per 100 ft. per minute at 100 lbs. per sq. in. A well-manufactured hose may be expected to lose only as little as half this quantity. Percolation increases considerably with rise in pressure, as is shown in Table II. The results are for new 2¾-in. diameter hose completely saturated with water.

TABLE II

Pressure in lbs. per sq. inch.	Loss in gallons per minute per 100 feet.
20	·027
40	·136
60	·441
80	·999
100	1·722
120	2·62
140	3·64

(ii) *Expansion of Hose.* When hose which has been laid out in a straight line is subjected to water pressure it increases in length. It is this increase which causes charged hose to "snake." When the pressure is taken off, the hose resumes its previous length. On tests of a number of samples of new unlined 2¾-in. diameter hose, the percentage increase in length at pressures greater than 80 lbs. per sq. in. was about 1 per cent. per 30 lbs. per sq. in. rise in pressure. A mean value for the increase in length of 100 ft. of hose when charged to 100 lbs. per sq. in., as compared with uncharged

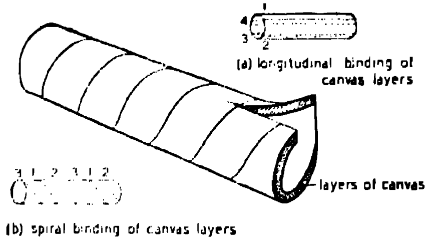
1
4
3
2
(a) longitudinal binding of canvas layers
layers of canvas
3 1 2 3 1 2
(b) spiral binding of canvas layers

Fig. 4. Sketch showing construction of duck-covered rubber hose and first-aid tubing.

hose would be about 6 ft., although individual samples may range between 2 ft. 6 ins. and 7 to 8 ft.

This increase in length emphasises the inadvisability of straightening out charged hose. Should a length burst and require to be changed the contraction of the line on release of pressure would pull the couplings of the lengths at either end so far apart that a new length could not be connected up.

2. COMPOSITE TYPES

(*a*) *1¾-in. Diameter Duck-covered Rubber Hose.* This hose was developed largely for first-aid firefighting. Owing to its smaller diameter it requires less water initially to charge it, it is non-porous, and hence its use results in decreased water damage, whilst it is less expensive than rubber-lined woven hose having the same performance. Its disadvantages are that it is rather heavier and that it is more bulky than unlined hose.

The hose is manufactured in 60-ft. lengths. It consists (Fig. 4) of an inner rubber tube of the desired diameter round which strips of rubberised fabric are applied, either in the form of longitudinal strips or as spirals. Usually four plies are employed to obtain the necessary strength. Standard instantaneous couplings (2½-in. diameter) are employed, so that the hose may be connected to hose of other types or diameters without the need for adaptors. Acceptance test pressure is 150 lbs. per sq. in.

(*b*) *First-aid Tubing.* This is a form of rubber tubing built to withstand internal pressure sufficient to yield a satisfactory jet at the nozzle. Its construction may vary considerably with different types, but in almost all cases it consists of an inner rubber tube having a diameter of approximately 1 in. reinforced either with spirally applied strips of fabric or with a form of braiding. It is then covered with an outer rubber skin. In some types there may be two layers of strengthening material separated by a further layer of rubber. First-aid tubing is made in a manner very similar to duck-covered hose and normally comes in 60-ft. lengths. If a braided reinforcement is used, the inner core is passed through a special machine which plaits this in position on the tube which is subsequently covered with its outer layer of rubber and vulcanised. Acceptance test pressure for first-aid tubing is 150 lbs. per sq. in. and at the time of publication of this *Manual* subsequent test pressure 100 lbs.

3. RUBBER HOSE AND TUBING

This type of hose is principally used in the Fire Service as wash-down tubing. Whilst this may be made as a light form of first-aid tubing it may frequently consist of rubber only. In the latter case

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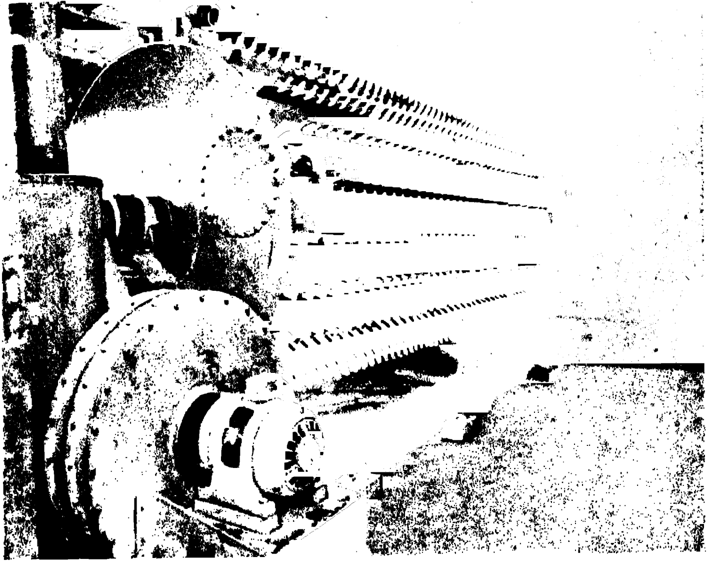

Plate 1. Dehydrator installed for drying hose under cover. Note, electric motor to drive fan, and standpipe heads for connecting unlined hose.

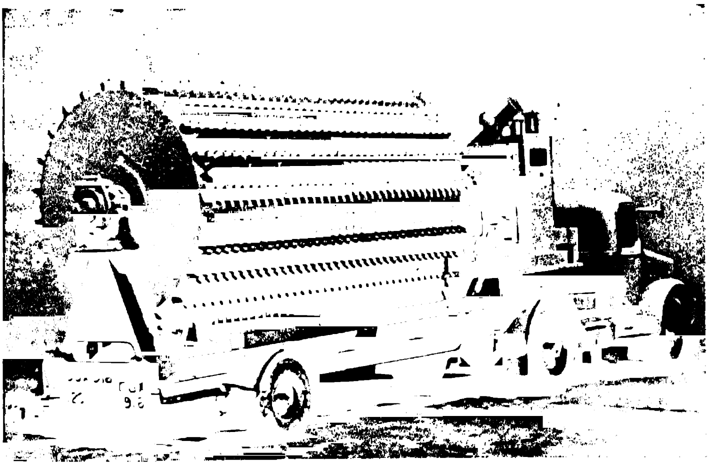

Plate 2. Mobile dehydrator. The trailer can be detached and the towing vehicle used elsewhere if desired.

Plate 3 Hose-drying cabinet. Note fan and heater unit (lower right) and thermostatic control panel on wall of cabinet.

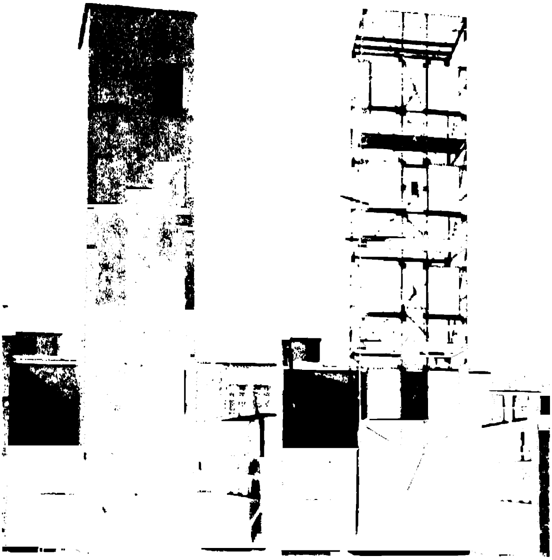

Plate 4. Drill tower providing hose-drying facilities. Left : completed. Right : under construction.

Plate 5. Two man hook ladder drill showing correct stance when using climbing hook type belt. Note the [illegible] grip of the lower man giving stability when elevating the second ladder.

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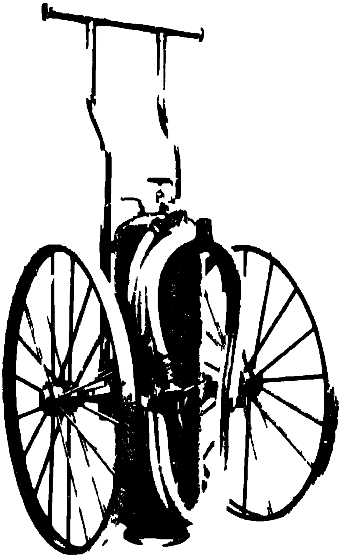


Plate 6 A typical chemical engine (foam type)

Plate 7 Rocking stretcher for use with a resuscitation set

it is "extruded" in continuous lengths, that is, the semi-plastic rubber prior to vulcanisation is forced under pressure through an annular steel die (*i.e.*, in the form of a ring), french chalk at the same time being introduced internally to prevent the walls sticking together should they touch. The tubing is then vulcanised and is ready for use. Specifications for wash-down tubing vary greatly, and it is impossible to deal with them here.

THE CARE AND MAINTENANCE OF HOSE

(a) Damage to Hose. Emphasis has been laid on the method of fabrication of hose in order that its liability to damage can be fully appreciated. In wartime, apart from considerations of cost, problems of supply make care of hose imperative, and this therefore plays a fundamental part in training. It is imperative that every man should know how to look after the hose in his care and how to keep it in first-class condition and ready for any calls which may be made upon it. Much of the damage caused to hose is avoidable by the strict carrying out of hose drill instructions, and every opportunity should be taken to impress on personnel the necessity for care in its use. It should be emphasised that a high degree of skill and wide experience are needed for the manufacture, testing and maintenance of hose. This should prove an added incentive to the careful and intelligent use of hose.

The causes of decay in hose may be listed as—

(i) Abrasion.
(ii) Mildew.
(iii) Shock.
(iv) Acids (particularly rubber acid), alkalies, oil and petrol.

(i) *Abrasion.* Men should always be taught to lay out hose without dragging. The question of abrasion is intimately connected with the methods of making-up hose, so that these will now be dealt with.

Methods of Making-up Hose. Numerous different methods have been developed for storing hose. These may be listed as—

(*a*) The roll (or coil) or variants of the roll;
(*b*) Flaking or variants of flaking.

THE ROLL OR COIL. In this method the hose is laid out flat on the ground and a start is made at the female coupling end if instantaneous couplings (Fig. 5, *left*), or the male end if threaded couplings, are fitted. The coupling is doubled down on the hose which is then rolled up until the further end is reached. The hose strap is then passed through the centre of the hose and secured about 6 ins. behind the outer coupling (Fig. 5, *right*). Rolled hose is normally to be preferred, since, particularly when instantaneous couplings are fitted, the female coupling may be held with both hands and the hose then rotates as it is run out. The correct position in which to hold a roll of hose is shown in Fig. 6. Unless the stop nut retaining the pawl and spring in the cap is secured by burring or by a small pin, running the hose out in this fashion may lead to the cap coming adrift. Rolled hose should always be stowed on edge (as shown on the *right* in Fig. 5) and never flat. If placed flat the edges are subjected to more than their fair share of the wear and tear. A roll

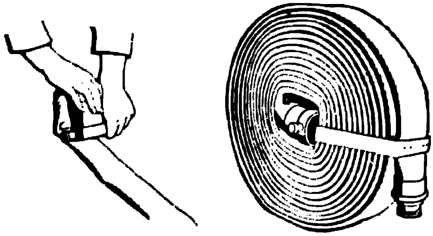


Fig. 5. Left : the correct method of starting to roll a length of hose with instantaneous couplings. Right : the roll of hose completed and secured with hose strap.

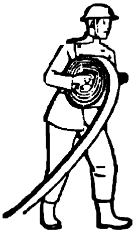


Fig. 6. Correct method of holding a roll of hose with instantaneous couplings for running out.

of hose, either wet or dry, should never be dragged along the ground. It may be the easy way but it is the wrong way. Rolled hose should always be carried.

Cases have been reported of damage being caused to unlined hose owing to the outer edge of the female coupling having cut the fibre of the hose when rolled, probably on account of the vibration of the appliance, on which the hose is carried, when in motion. In order to obviate any risk of such damage the female couplings should be examined, and, if there is a sharp edge, it should be smoothed off by filing. The vibration of the vehicle on which hose is stowed may also lead to chafing, in particular, where hose is in contact with the sides of the hose locker. Steps should be taken to avoid this as far as possible by careful stowing and by packing the hose with protective strips where chafing might occur.

Dutch Roll or Roll on the Bight. The hose is stretched out flat on the ground and the male coupling end if instantaneous couplings, or the female coupling if thread couplings are fitted, is then drawn back along the hose toward the other end so that the coupling lies about 3 ft. short of the coupling below (Fig. 7). The hose is now rolled up from the bight so that both couplings come together on the outside of the roll. With this method the hose may be run out very quickly, since a pull on either coupling causes it to unwind without tangling and both couplings can be pulled at once. This, however, causes severe abrasion of the edges and should not be allowed. It may also be used to give a long bight to allow the branch to advance without adding hose. For this purpose both couplings can be held and the roll given a push, when it will roll out and uncoil itself, leaving a long loop of hose. This is the only method of running out the Dutch roll which should be permitted. The disadvantages of this method of rolling are discussed later.

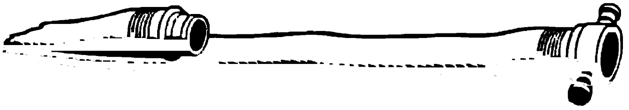


Fig. 7. Correct layout of couplings for making a Dutch roll.

Flaking. In this method the hose is doubled back and forward on itself and is subsequently secured at the centre of the folds (Fig. 8, *left*). Its principal advantage is that it permits of running out as fast as a man can move. Flaked hose is subject to the risk of serious damage due to dragging, particularly over broken glass. This may, to a considerable extent, be obviated by carrying the hose on the shoulder and allowing it to pay out as the man moves away.

The objection to flaking, however, does not apply to hose carried on special hose-laying vehicles, as there is little likelihood of dragging when hose is laid from such vehicles. Hose should never be flaked when wet since flaking causes undue strain at the bends.

Figure-of-Eight. This is a variation of flaking, but it avoids the sharp bends. As the name implies it is wound in a figure-of-eight pattern over two bollards (Fig. 8, *right*). Its chief advantage is that it avoids the tight bends of flaking and the hose can be run out equally well. On the other hand it takes up considerably more room. This method is undoubtedly the best for storing rubber-lined hose.

General Considerations. Considerable damage is caused by abrasion of hose lengths on rough surfaces, even a concrete yard being rough in this sense, and abrasion is liable to take place more readily and more rapidly when the hose is wet. Points particularly affected are at bends and on the edges of flattened hose. Therefore hose should never be dragged along the ground if it can be carried, and it should never be pulled round a corner where it may scrape against a wall. Sufficient slack should be available at the branch so that it may be worked forward without dragging the entire hose line.

The vibration of a pump in continued action may subject the first length of delivery hose to severe chafing at the first point where it touches the ground. A hose bandage or a short piece of old hose (carried for the purpose), or even sacking, wrapped around at the point of contact, should be fitted to protect the hose from damage.

(ii) *Mildew.* Mildew is a fatal cause of deterioration of hose whether lined or unlined. Its onset is insidious and frequently its presence can only be detected by the most careful and minute examination. It is not unknown for an apparently sound piece of hose to be so weakened by mildew that it can be pulled apart in the hands. No effective preventative against mildew has yet been developed. Burnettising, however, has some effect and also adds considerably to the pliability of the fibres. No rot-proofing solutions which will not weaken the fibres have yet been found effective for treatment and most so far tested tend to lock the warp and weft threads thus reducing flexibility and subjecting the yarns to undue strain when the hose is handled.

From examination of samples of infected hose it appears that the

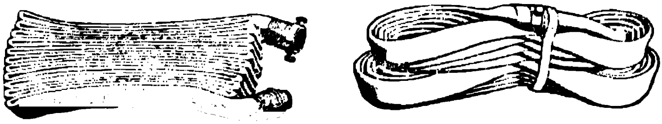


Fig. 8. Left : flaked hose. Right : hose made up as a figure-of-eight.

tendered areas to which leaks are due are caused in some cases by infection with moulds which render the fabric of the hose locally weak and unable to stand up to water pressure. Most tendered areas are localised at or near the margins of the hose, and the initial damage is almost certainly due to mechanical causes, such as friction or undue marginal compression.

It is probable that such damage renders hose more susceptible to mildew infection than it would be if intact, but the possibility of direct infection of undamaged hose cannot be ruled out. One feature which became evident at an early stage during investigation was that a certain optimum moisture content of the hose fabric was necessary for rapid and severe infection. Complete saturation prevented active infection as readily as complete dryness, and it seems to be established that imperfect drying provides conditions necessary for severe infection. If suitable drying of fire hose can be guaranteed there need be no mildew problem.

It should be noted that complete or absolute dryness can only be attained and maintained where the surrounding atmosphere is completely dry. Absolute dryness would weaken the hose.

In 1938-39 the following experiment was carried out :—

Of two 3 ft. pieces of new 2¾-in. rubber-lined twill woven flax hose, one was kept in the relatively dry hose room, the other was hung in the open under head cover for 12 hours for " conditioning." The following are the results of destruction tests carried out on the pieces.

	lbs. per sq. in.
Hose room pieces .	875-775-900-750-750-800
Conditioned pieces .	950-1100 975-1000-1000-950

It seems reasonable to assert that conditioning does increase substantially the pressure resisting and tensile strength of hose. The fundamental necessity is therefore to carry out instructions regarding early cleaning and reasonably quick drying preferably in a current of air, at the same time being careful to note the difference in treatment and temperatures for unlined and lined types. When stowing in appliances or storing in the hose room, adequate ventilation must be ensured by opening the shutters, etc., on hose lorries, lockers and boxes on other appliances and by all methods practicable in hose stores. These precautions should ensure conditioning and prevent mildew.

(iii) *Shock.* It is not generally realised that shock is a frequent cause of hose failure. Hose should invariably be treated with care, and rolls of hose should never be thrown roughly to the ground even though they may be dry and in good condition. Shock may, of course, also arise when water is allowed to flow too rapidly into a line of hose which is badly kinked or when a shut-off type branch is operated suddenly. The sudden straightening out of hose under the pressure and the ensuing rush of water which flows only to be checked by the next kink, sets up a series of pressure waves which may easily lead to collapse at a weak point.

(iv) *Acids.* Recent researches have disclosed that much damage to rubber-lined hose is caused by what has been termed rubber acid. This is formed by the action of a micro-organism on the sulphur used for vulcanising the rubber and consists of dilute sulphuric acid. As the water is evaporated from the acid through slow drying out, so the concentration increases. A strength may easily be reached in practice where, should the acid come into contact with the jacket of the hose, it will cause serious weakening, accompanied sometimes by the appearance of yellowish or brownish stains.

(*b*) *Care of Hose.* The following are general hints, applicable in particular to the care of rubber-lined hose, which will assist in prolonging its life.

(i) New hose should never be allowed to remain in the cases in which it is received, but should be removed and the coils loosened.

(ii) Hose which is unused for long periods of time should not be allowed to remain on the appliances, but should be removed and placed on racks or towers.

(iii) When storing hose, short bends should be avoided as much as possible. If it is necessary to store the hose in folds, the bends should be moved now and then to prevent the fabric, and in particular the rubber lining, from taking a permanent set at the bends.

(iv) Rubber-lined hose should have water passed through it from time to time to keep the lining in good condition, after which it should be thoroughly drained, and dried in towers or by hanging in a warm room. Rubber acid stains, or canvas of hose suspected of having been in contact with the acid, should be thoroughly washed in clean, cold water. No attempt should be made to neutralise the acidity of the canvas by treatment with alkalies.

(v) If hose becomes frozen it should on no account be bent, as it will be liable to crack.

(vi) Rubber deteriorates at low temperatures, and it is equally liable to damage from heat. Rubber-lined hose should not be exposed to hot dry air nor stored in the sun's rays.

(vii) Great care should always be taken of rubber-lined hose, especially when cooling down after large fires, as the hose is often stretched over débris fallen into the building, and, as the bricks and stone, etc., retain heat for a long time, the outer covering is liable to scorching, so weakening it and shortening the life of the hose. Also, it is easily damaged by contact with petrol, oil, grease or acid, and special care must be taken to keep these materials away from hose, particularly that kept on motor appliances. Petrol, for instance, will cause the rubber to separate from the fabric.

(viii) Hose should ***never*** be bent or kept at too acute an angle, especially under water pressure, since this causes a severe strain on the fibre, and is a frequent source of actual breakage, particularly if the edge under strain is rubbed sharply or knocked against a hard surface.

(ix) Hose which is laid across roads should always be ramped to prevent damage by passing vehicles. There are several types of ramp in use. These are described in Chapter 5 on "Hose Fittings." Every pumping appliance should carry ramps, the number and disposition of which will vary greatly with the accommodation available.

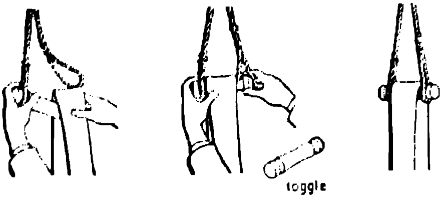


Fig. 9. Placing the bight of a length of hose on a hose whip toggle.

(c) *Cleaning Hose.* Whenever hose is returned to the station after use it is essential that it should be washed with the greatest care to remove all particles of grit which may have become caught up in the outer fabric. On no account should chemicals of any sort, soap, or other material, be used in these cleaning operations, except as mentioned below. The hose should be laid out straight and flat on a clean surface and pure water applied without force. Careful scrubbing with bristle brooms is sufficient to ensure the well-being of the hose. The brooms used should, as far as possible, have long bristles and not be too stiff, otherwise the grit may be brushed with such force that it cuts the fibres. The motion of the brush should be from side to side and not lengthwise, since, owing to the construction of the hose, the tendency would be for particles to become lodged in the weft.

Experiments have, however, shown that the fabric of hose which has become begrimed with grease or oil can be cleaned effectively if the hose is scrubbed thoroughly, with a solution of soft soap and soda in warm water, and afterwards very thoroughly rinsed in clean cold water. When hose is thickly coated with gummy rubber, grease, etc., fine sawdust can be used to amalgamate with the soiling matter and rubbed off without damage to the hose. This was proved to be simple and effective following the Colonial Wharf fire in London in September, 1935.

When the hose is thoroughly clean it is best drained by attaching one coupling to a hose whip and running it up the hose tower. Alternatively, lengths of 75 ft. and upwards should be folded coupling to coupling, the hose whip toggle inserted in the bight as shown in Fig. 9 and the hose then hung double. When lengths are frequently used, washed and dried, the position of the bight on the toggle should be varied from time to time. The preliminary drying may be effected in the tower and the hose later transferred to the hose drying room.

When under-running, particularly unlined hose, it is essential to see that kinks do not form at the bends. These kinks may lead to the formation of pockets of water or, alternatively, pockets of vacuum, and thus prevent the complete removal of the water. On no account should men be allowed to walk on hose in order to flatten it out or rid it of water before rolling. This not only drives any flint or grit which may be present right into the fabric but imposes a heavy strain on the fibres on either fold which considerably weakens the hose. In practice it is found that bursts almost invariably appear at the two opposite points on the diameter where the hose has been flattened. With lined hose avoidance of such treatment becomes of even greater importance, since its result is that not only are the fibres of the casing weakened but the lining itself becomes fretted, and particles of dirt, etc., lodge in these frets and a rapid deterioration of the rubber then sets in. The correct method of clearing the water by under-running is to raise the hose shoulder high (Fig. 10) at the same time avoiding kinks which will trap the water.

(*d*) *Drying*. Methods of drying may be divided into :—

(i) Natural.
(ii) Mechanical.

(i) *Natural.* The most satisfactory natural method of drying hose, whether lined or unlined, is in suitably constructed hose-drying premises which are fully ventilated and yet which do not admit rain. Such hose-drying arrangements must depend to a very large extent on local conditions and on local ingenuity. At most stations where firefighting equipment is housed, if a hose tower is not available it is possible to hang the hose from a bracket attached to an outside wall, preferably a wall facing south, subject to the proviso that rubber-lined hose should not be exposed for any considerable length of time to direct sun rays in hot weather.

The bracket should be fitted with a pulley block. A line (the hose whip) should be rove through the pulley block and one end should terminate with a wooden toggle about 8 ins. long. The standing part of the line should be spliced round one end of the toggle. A short length of line having an eye should be spliced into the standing part of the line, thus serving the other end of the wooden toggle over which the hose would be placed prior to hauling aloft. The spare end of the line should be secured close to the toggle, thus making an endless line for ease of working. Hose-drying towers combined with drill towers having one or more sides weather-boarded, have also been in use for some years, and have been found to serve satisfactorily (Plate 4).

Drying sheds might be built on the side of a building with louvre walls, so arranged as to permit of the entry of as much air as possible. Hose might be laid horizontally on racks or hung in folds. If the latter, it should be noted that for all hose careful under-running is essential to remove all the water possible.

Another method of drying hose is to flake it over poles suspended from the roof of a room (*e.g.*, a recreation room or lecture hall) where there is plenty of ventilation, and, preferably, some form of heating. When this method is used care should be taken to secure the hose firmly to prevent its being damaged by abrasion, and the couplings should also be lashed.

(ii) *Mechanical Drying.* A number of mechanical hose-drying methods have been developed, according to the ideas of various manufacturers. The basic principles are, in every case, the same and consist of the application of warmth and

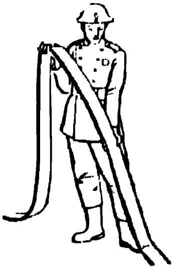


Fig. 10. Correct method of holding hose to under-run.

the passage of an adequate current of air, to carry away the moisture. The means whereby this is effected in the various types of hose-drying machines differ.

DEHYDRATOR. The dehydrator consists of a rotatable steel drum running on bearings and driven by a small-geared motor at approximately 30 revolutions per minute. This metal drum is fitted with slotted wooden racks upon which six 100-ft. lengths of hose can be wound, each of which is connected to a short standpipe fitting of which six are carried on the drum. Warm air is supplied to the drum under 1¼ lbs. per sq. in. pressure from a fan, which is driven by an 8 h.p. petrol engine. Before entering the drum the air is driven through a heating chamber warmed by a crude oil burner, and is then circulated inside the drum to heat the walls, before passing through the standpipes to the hose. A number of small holes are drilled in the circumference of the drum, in line with the hose, through which a proportion of the air is blown as warm jets on the underside of the hose.

The dehydrator dries the hose by five distinct and simultaneous methods, *i.e.*—

1. By blowing warm air under pressure through the hose, thus drying the interior surfaces.
2. By direct radiant heat from the heated metal drum on which the hose is wound.
3. By blowing jets of warm air on the underside of the hose.
4. By rotation of the drum carrying the hose, thus draining the hose by gravitation.
5. By free air currents caused by rotation of the hose and drum.

By using the dehydrator six 100-ft. or twelve 50-ft. lengths of hose can be dried in from one to four hours in any weather, a slight amount of cleaning being accomplished in the same operation, in the case of unlined hose, by the action of the air in expelling dirt from the fabric.

There are several types of dehydrator in use in the Service (Plate 1), including the "large" "standard" and "baby" fixed installations, and the mobile model recently introduced (Plate 2). All these models work on the same principle, and the construction is as outlined above. In some of the earlier models an electric motor was used to drive the fan in place of the 8 h.p. petrol engine now standardised; and on the "standard" and "baby" models no motor is provided for revolving the drum, which is accomplished by means of air flutes at the other end of the drum from that at which the air enters. The speed at which the drum revolves is controlled by the extent to which the flutes, which are manually operated, are opened or shut.

Dehydrators are normally operated at 160° F., the temperature being taken at the heating chamber, which is fitted with a thermometer for this purpose. When drying rubber-lined hose this temperature can be modified to suit individual requirements. Satisfactory results have been obtained operating at 120° F., at which temperature of course it takes longer to dry a full load of hose.

Undue heat is dangerous to rubber-lined hose, but it should be appreciated that by the time the air reaches the hose it has fallen considerably in temperature from that registered at the heating chamber. It is recommended, however, that when drying rubber-lined hose the couplings should not be connected to the stand-pipe fittings (the outlets of which should be closed with the blank caps provided). Drying will then be accomplished by exterior heat and air currents only.

HOSE-DRYING CABINET. Other hose-drying machines work on the principle of a cabinet in which the hose is contained in long bights (Plate 3). The interior of the cabinet is then warmed and ventilated by means of heaters and fans. Arrangements are usually made that the temperature cannot rise above a predetermined point, usually fixed at approximately 100° F.

When hose is thoroughly dry it should be soft and flexible. If not, it should be sent back for further drying. Rubber lined hose which is suspected of contamination by rubber acid should not be dried by mechanical means except in emergency since the rotting effect of the acid is markedly accelerated by heat.

(e) *Repairing Hose.* Immediately hose is returned to a station after use it should be tested and carefully inspected for damage before even washing is undertaken. Any lengths which require repair should be set aside. Where possible, minor repairs to the hose should be carried out at the stations by members of the Service. This not only demonstrates the necessity for care in handling hose but decentralises the amount of repair work to be carried out. The most common damage to hose consists in pinholes. These may be repaired by darning or by patching.

(i) *Darning.* Hose darning outfits are available and have been issued to the Service. These can be used if necessary to repair pinholes under pressure immediately they occur and on the spot (Fig. 11, *left*). The object of issuing the sets is to facilitate the *immediate* repair of small defects, so that holes or bursts do not develop and the life of the hose is prolonged. It is only suitable for repairing very small holes.

Sail-maker's yarn, rove, condenser yarn or yarn stripped from discarded hose can all be used as the repairing agent with the needles.

If the needle supplied with the set should break, a convenient and satisfactory method of replacing it is to cut a heavy darning needle of suitable diameter to the correct length and solder it into the nipple of the broken needle.

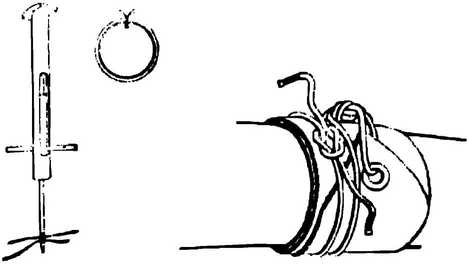


Fig. 11. Left : a hose darner showing yarn in place. Right : a typical hose bandage in position on charged hose.

Hose can also be

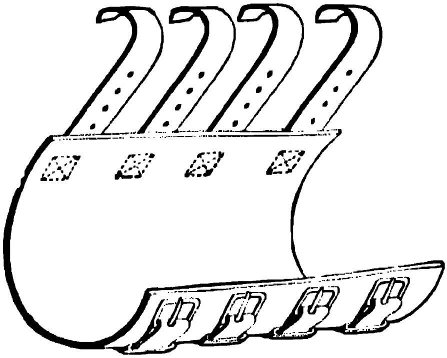


Fig. 12. Typical hose gaiter.

permanently repaired by darning. The equipment required is a bent awl, a needle, a knife, and some strands of hemp. The needle should be threaded with four strands of hemp and the ends cut level. The operation is carried out in the same way as darning a sock, the hemp being used to re-make the broken strands of the hose.

To replace a broken warp the weft should be lifted with the awl, and the hemp threaded under and over the weft alternately. If more than one strand has to be renewed, subsequent strands should be threaded on either side of the first, but where the first strand went under the weft, the second should go over and so on, so that the pattern of the weave is maintained. If it is necessary to replace both warp and weft, the weft should first be renewed by threading new hemp under and over the warp, and then the warp replaced as described above. When hose has thus been darned a patch should be affixed over the darn for extra protection.

Lugless Coupling. Where a serious burst makes repair by patching impossible, but the remainder of the length of hose is in sufficiently sound condition, the damaged section may be cut out. If it is close to a coupling then the coupling may be rewired on to the length. If, however, it is near the centre or at such a distance from either end that too much sound hose would be wasted by cutting out, then the two sound pieces may be joined by the use of a lugless coupling. A description of this coupling will be found in Chapter 5.

In many instances a length of hose with a lugless coupling will give first-grade service, since the grade depends upon the general condition of the length. As a lugless coupling reduces the flexibility of a length of hose it should be inserted at the end nearer the pump, thus coming near the female end coupling in the case of round- or V-thread, or near the male end if instantaneous. To ensure this, the end couplings should, if necessary, be switched when putting in a lugless coupling. If this rule is followed out it will ensure that a length with a lugless joint, used as a branch length, will possess maximum flexibility and be subject to minimum friction.

(ii) *Hose Gaiters.* Larger holes in hose which cannot be repaired by darning should be temporarily repaired while the hose is in use by placing a gaiter round the leak. This will prevent the hose from bursting and will also save water running to waste. Several types of such gaiters are in use in the Service, the most common being the hose bandages issued in large numbers to the National Fire Service. These consist of 2-ft. lengths of canvas approximately 3 ins. in width fitted with a brass eyelet at one end. Lengths of twine are secured to this eyelet and used to lash the bandage in position after it has been wound round the hose over the leak (Fig. 11, *right*). Leather gaiters fitted with straps and buckles (Fig. 12) are also used for the same purpose.

A cheap and serviceable gaiter can be made from a piece of discarded 2¾ in. unlined hose, about 16 ins. long, slit up its length, so as to open out, with three brass eyelets (⅜ in. holes) inserted along one of the short sides. A piece of cord about 2 ft. long, knotted centrally to each eyelet, serves to tie the gaiter after it has been bandaged round the hose.

(iii) *Hose Jacket*. A more efficient temporary repair than any of the above can be effected by means of a fitting known as a hose jacket. This consists of a cylindrical rubber-lined metal casting about 1 ft. long, which is hinged down the centre and fitted with a strong spring-loaded locking clamp (Fig. 13). The damaged portion of the hose is laid in the jacket in such a way that only the point of fastening meets the water issuing from the burst. The sides of the jacket are then brought sharply together with sufficient force to overcome the pressure of the water and automatically lock in position. If the water is allowed to strike the walls of the jacket during this operation the pressure will prevent it being closed. The rubber lining is designed to form a seal at all points of closure and a watertight repair is consequently effected. The chief drawbacks to this type of jacket are cost, size, and the fact that a special jacket must be carried for each size of hose. Hose jackets of this type are particularly valuable for preventing water damage if a length of hose develops a leak when working inside a building.

(iv) *Patching*. Such leaks can be satisfactorily repaired by hose patching if the hose is generally in good condition and the workmanship is good. The patch is applied in exactly the same way as is employed for repairing motor-car inner tubes. The hose is first carefully cleaned and a prepared patch is then placed over the hole. The hose and patch are then placed in a vulcaniser and heat is applied for the specified time. Special hose vulcanising outfits are now available (Fig. 14), but whilst they have proved extremely satisfactory they are dependent on either electricity or gas, neither of which may be available under war conditions. Much development work has been carried out with

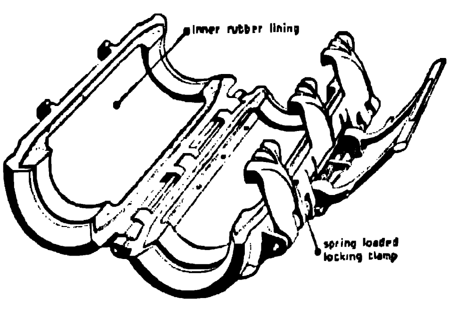


Fig. 13. A typical hose jacket.

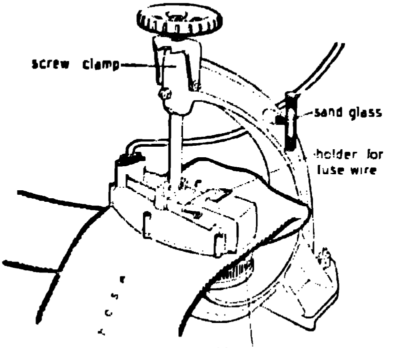


Fig. 14. Sketch of one type of vulcanising outfit. This model employs electricity for heating. When the vulcaniser reaches the correct temperature the fuse wire in the holder melts and breaks the circuit. The sand glass timer is then reversed and when the sand has run through, the clamp is released and the hose removed.

a type of patch which can be applied solely with the use of a hot iron or by means of heat generated by burning a small specially prepared charge, and hose repairs with this type of equipment are now being satisfactorily effected.

Wherever possible, major repairs to hose should be carried out by specialists. Skilled examination is necessary to detect latent damage, to replace lengths beyond repair and to ensure that the field force is equipped with reliable hose. Damage is varied, often difficult to detect and repair, and skill, experience and equipment are required to carry out efficiently this very important branch of fire equipment maintenance.

SUCTION HOSE

Suction hose is the name applied to hose designed to resist external pressure. It is used exclusively between the water supply and the pump. As it will withstand pressure either internally or externally it can be used when working a pump either from a pressure-fed or from a static supply. Armoured suction hose or "suction," as it will be termed from now on, is an essential part of the equipment of every pumping appliance.

1. CONSTRUCTION

The lengths and diameters of suction vary with the appliances on which it is carried, but the construction is substantially the same in every case. The principal feature is that it should possess sufficient strength to withstand without collapsing the pressure of the external air when a vacuum has been created inside ; and should be strong enough to resist the maximum hydrant pressure normally encountered, and at the same time should possess the maximum of lightness and flexibility compatible with this strength.

Suction supplied to the National Fire Service (Fig. 15, *left*) is built up from a tough rubber lining in which is semi-embedded a spiral made from 10 S.W.G. highly tempered galvanised steel wire. The embedding of this internal wire is so arranged as to provide a full waterway and a relatively smooth internal surface. In certain makes of suction the internal wire is not embedded in the rubber but projects into the waterway. Whilst this possesses some advantage from the point of view of manufacture, it is unsatisfactory hydraulically and leads to very considerable friction losses. The reinforcing wire is not fully embedded owing to the difficulty of obtaining a sufficiently strong bond with the inner lining. Under prolonged working with low internal air pressure a separate lining would tend to pull away and might block the hose.

The exterior of the hose is built up from several layers of canvas with, in most cases, an external semi-embedded wire of the same material as the internal wire. The two spirals are so arranged that they lie midway between each other. This outer covering is vulcanised to the rubber lining.

Suction as issued to National Fire Service appliances is tested to an external pressure of two atmospheres, and an internal pressure of 150 lbs. per sq. in. There is, therefore, no danger in using it to connect a hydrant to the pump inlet provided that the static hydrant pressure is below 90 lbs. and provided that the hydrant valve is opened slowly to avoid shock.

Suction carried on appliances of less recent manufacture, however, was not in many cases designed to withstand internal pressures of this order, and *should not* therefore be used on pressure supplies where there is any possibility of damage.

2. TYPES OF SUCTION

The following types of suction have been issued to the National Fire Service :—

Internal diameter (inches)	Length (feet)	Thickness of canvas	Fitted with double wire reinforcement	Issued with
1½	10	2-ply	No	Two-man manual.
2	6	3-ply	No	Light portable pumps.
3	8	5-ply	Yes	Heavy and extra heavy self-propelled pumps (short length for use to connect to hydrant).
3	10	5-ply	Yes	Heavy pumps on trailers (short length for use to connect to hydrant), light pumps for general use.
4	8	5-ply	Yes	Medium and large T.P's.
4	10	5-ply	Yes	,, ,, ,,
4	15	5-ply	Yes	,, ,, ,,
5½	8	5-ply	Yes	Heavy self-propelled pumps.
5½	10	5-ply	Yes	Heavy pumps for boats, heavy pumps for trailers.
6½	8	6-ply	Yes	Extra heavy pumps for boats and trailers.

Variations in this allocation may be encountered, due to problems of supply when the equipment was first issued.

Suction hose used in some localities, however, may differ considerably from the above specifications. It was customary for many manufacturers to construct suction for appliances in two long lengths, which varied from 14 to 16 ft. and which could be stowed conveniently one along each side of the machine, rather than in the three or four shorter lengths found convenient for stowing on

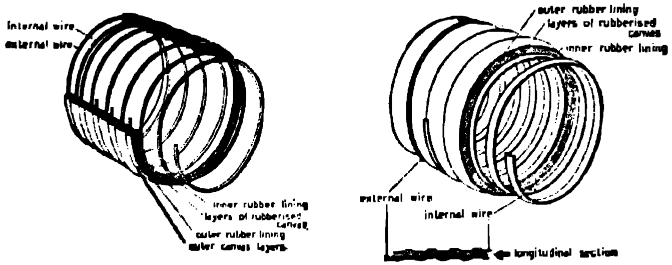


Fig. 15. Left : cutaway view of suction as supplied to the National Fire Service. Right : suction with flattened wire reinforcement.

appliances such as trailer pumps. The suction itself was frequently made throughout from vulcanised rubber, and the strengthening was applied by different methods—by means of flat spirals of steel in place of wire (Fig. 15, *right*), or by totally embedding the reinforcement. The principle of construction is, however, in most cases the same.

3. CARE OF SUCTION

Since suction hose consists largely of rubber, care and maintenance are simple. It should not be exposed to direct sunlight for prolonged periods and should be kept preferably in a cool place and have water passed through it at intervals of not longer than one month. Canvas or fabric-covered suction should not be scrubbed, as this tends to fray the material and may result in pinholes ; nor should dressings which might cause the rubber to perish be employed.

A point calling for particular attention is that when suction hose is carried externally on an appliance it should be protected as far as possible from damage by men standing on it or clambering over it when mounting the appliance. Improvised covered racks, sacking, or the provision of proper steps for mounting, will greatly reduce damage due to these causes. In some localities it was the custom to protect the suction by encasing it in a tightly fitting jacket of canvas which could be renewed as necessary.

Suction couplings should be treated with particular care, as even slight distortion may cause air leaks. The couplings should never be dropped or dragged along the ground, and the correct size wrench should always be used for tightening the joints.

4. TESTING

At the time of publication of this *Manual* suction is tested monthly. After verifying that air leaks are present in pump or suction by means of the dry vacuum test, the leaks are located in the suction hose as follows :—

All lengths of suction hose are to be connected up and placed under hydrant pressure, care being taken to shut off the vacuum gauge. All blank caps are to be removed from deliveries. One delivery is to be opened to allow air to escape. The delivery is then shut down gradually and hydrant pressure applied to the suction ; pressure not to exceed 90 lbs. per sq. in. Any leak which may exist will be indicated by water, and steps are to be taken to rectify it.

5. REPAIRS

Once damaged, suction hose is extremely difficult to mend. Bending at too acute an angle or too heavy a weight carried on it may displace the reinforcing wires which, being of tempered steel, cannot be restored to their correct place. The only repair possible is complete rebuilding, equivalent to the production of a new length of suction. Small leaks (pinholes, etc.) due to wear, shell splinters, etc., may be mended by the application of a suitable patch, as for rubber-lined hose.

6. SOFT SUCTION

For ease of reference the term " soft suction " is often used for delivery hose employed on the intake side of a pump. These lengths are coupled up to the pump inlet either by means of the collecting head or a suction hose adaptor (see Chapter on " Hose Fittings "). The construction of the hose and its fittings, and care and maintenance, are precisely the same as for ordinary delivery hose. Soft suction can only be used with a pressure-fed supply, since any reduction of the internal pressure below that of the atmosphere would cause the hose to collapse. Where hydrant pressures are considerable and flows good, however, soft suction is commonly used. Being delivery hose, it is capable of withstanding considerably higher internal pressures than those types of armoured suction hose, which were constructed primarily to withstand external pressure. Further advantages are that it is cheap (good parts cut from a condemned length of delivery hose are frequently used), it is easy to run out and convenient to stow on the appliance.

The lengths of soft suction employed depend to a considerable extent on local preference—from 20 to 30 ft. is very usual. If additional distances have to be covered, lengths of delivery hose are utilised as required and two or more pressure supplies can be connected to the pump through a collecting head.

PART I CHAPTER 5

HOSE FITTINGS

OWING to the wide range of hose fittings employed by the Fire Service it is difficult to preserve a logical sequence when describing the various types. To obtain some continuity, the various fittings are taken in the following order: couplings; adaptors; breechings; branches, nozzles, and branch holders (including radial branches, monitors and deluge sets); collecting heads and foot valves; hard suction fittings; standpipes; and hose ramps.

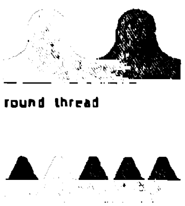
Ex-regular brigades throughout the country possess many items of equipment peculiar to themselves, and it is impossible to give more than a general description of the more important of these fittings. Detailed descriptions have been reserved for apparatus in general use throughout the Fire Service.

COUPLINGS

Generally speaking, any metal fitting for joining two lengths of hose together, or any piece of apparatus to a length of hose, or *vice versa*, is termed a coupling. For other types of union, such as the joining of a nozzle to a branch, the term connection is used.

1. DELIVERY HOSE COUPLINGS

At each end of a length of hose are attached metal fittings termed hose couplings. These are divided into two main groups determined by the joint, which may be obtained either by means of the screw principle or by some method of interlock. The complete coupling consists of two fittings, one attached to each end of the hose. With the exception of one type of interlocking coupling these two fittings are named the male and female coupling respectively. The question whether an outlet or inlet is male or female is governed by the group to which it belongs, *i.e.*, all outlets in the screw system are male and inlets female, whereas in the standard instantaneous system all outlets are female and inlets are male.


round thread

'V'-thread

Fig. 1. Round and "V" threads.

(a) Screw Type Hose Coupling

(i) *Round and "V" Threads.* Two types of thread are used on screwed hose couplings, a round thread, often known in the Fire Service as the "large round thread" or "London Fire Brigade round thread," and the "V" thread. To secure interchangeability of couplings of the same type the dimensions of these threads have been standardised and are laid down in British Standard Specification No. 336. The difference between round and " V " thread is shown in Fig. 1. In the standard patterns the former has 2 and the later 5⅛ threads to the inch.

The male screw coupling (Fig. 2, i and iii) for joining delivery hose is a metal casting or forging (usually, in all types of coupling, of gunmetal, brass or bronze, but sometimes of aluminium for lightness) in tubular form, externally threaded at one end for connection to a female coupling and externally serrated at the other for permanent attachment to a length of hose. The serrated end is known as the tail or shank, (*a*), the teeth of the serrations (*b*) pointing towards the threaded end of the coupling. The size of the coupling is known by the nominal size of the marrying portions and not by the internal diameter of the waterway, which is usually slightly less. The size of hose with which it is used, however, is determined by the external diameter of the tail from the tip of the first serration.

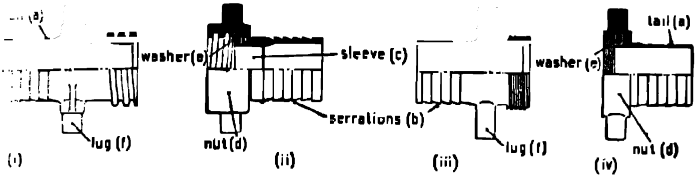


Fig. 2. Delivery hose couplings : round thread and " V " thread. (i) Round thread, male ; (ii) round thread, female ; (iii) " V " thread male ; (iv) " V " thread, female.

The internal diameter of a male round thread coupling decreases somewhat in the larger types from the commencement of the tail to its narrowest dimension, ⅜ in. from the orifice of the threaded end.

The female screw coupling of the round-thread type (Fig. 2, ii) consists of three separate castings, the tail (*a*), the sleeve (*c*) and the nut (*d*), a washer (*e*) being inserted between the nut and sleeve to provide a watertight joint. The tail (*a*) is serrated at one end and is tied into the hose in the same manner as the male coupling ; at the other end it is internally threaded with a fine " V " thread. The sleeve (*c*) is externally threaded at one end for engagement with the tail and is fitted at the other with a flange which engages with the rim of the nut (*d*). The nut is internally threaded to receive the male coupling. To assemble, the nut (*d*) is passed over the external thread on the sleeve (*c*) (the square-sectioned washer having first been inserted) and the tail is then screwed on to the sleeve.

The female coupling of the " V " thread type (Fig. 2, iv) is similar in essentials, but the tail and sleeve are cast in one piece, and the nut is therefore held in position by the washer only, which allows it to turn freely in either direction but prevents it becoming detached from the sleeve.

These couplings are lubricated with blacklead or graphite applied over a thin coat of terebine and then polished with a brush.

The round-thread coupling was used chiefly by the land appliances on the former London Fire Brigade whilst the " V " thread was used in a number of localities.

All sizes of this coupling, except when fitted to suction hose, have two fixed lugs (*f*) fitted in line on either side of the coupling. These lugs are used for tightening up or for breaking the joint in conjunction with a special type of " C " spanner known as a hose spanner. This spanner is curved to the approximate diameter of the hose coupling on which it is to be used, and has a hole through the curved end which fits over the lug and permits the spanner to grip the coupling. Two spanners must be used, one on either coupling, to prevent the couplings rotating as they are married or broken. Sometimes the spanner has at its other end a wrench for unscrewing the nozzle from the branch (see later). It is then known as a hose and nozzle spanner (Fig. 3). This type of spanner is issued to each operational fireman in those areas where threaded couplings are employed.

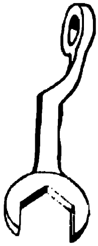


Fig. 3. Hose and nozzle spanner.

The coupling may be tied into the hose by means of a hose coupling binder such as that illustrated in Fig. 4 (i) ; the method of binding described below is representative.

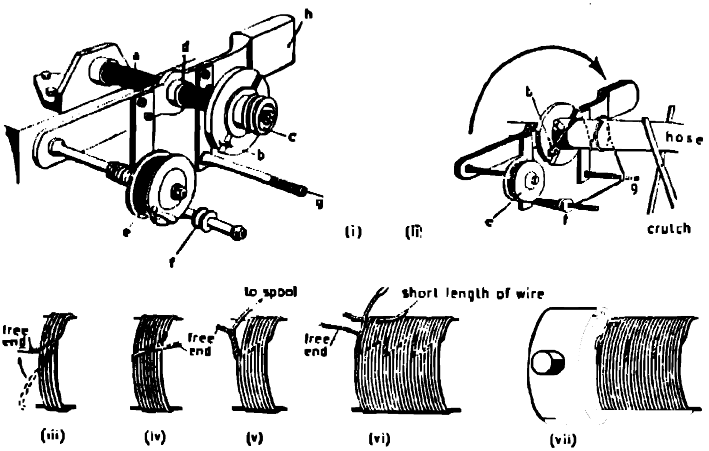


Fig. 4. Hose coupling binder : (i) general view ; (ii to vii) stages in the binding process.

A fixed threaded supporting spindle (*a*) attached to a bracket screwed to a bench has at its outer end a plate with a holed anchoring pin (*b*). On the outer side of this plate is an interchangeable adaptor (*c*) to which the coupling is fitted. The hose to be attached is supported on an X-shaped wooden crutch, and a piece of canvas, or sometimes leather, is laid around it where the binding will fall, to protect the hose from damage by the wire. After the hose has been drawn on to the tail of the coupling it is frequently secured to the tail by one or more rivets preparatory to tying in.

The whole of the apparatus except the plate and adaptor revolves around a threaded pivot (*d*) on the spindle. From the spool of wire (*e*) under tension the free end is led beneath the guide wheel (*f*) and grooved guide (*g*) over the coupling, and threaded through the eye of the anchoring pin (*b*). The wire used is 16-gauge copper or mild steel.

The operator, standing on the right, puts on a turn by swinging round in a clockwise direction the weighted arm (*h*) which has been moved to the adaptor end of the threaded spindle. This turn is adjusted so that the second turn, the first of the binding proper, will come just inside the extreme serration on the tail of the coupling. The second comes over the first turn (Fig. 4, ii), as do those that follow, the pivot travelling down the thread as the turns are made. When four turns have been put on (Fig. 4, iii), the free end of the binding wire is removed from the anchoring pin and pulled up towards the operator, and the binding is continued over it as before. After the eighth turn (iv) the free end is pulled over, hammered against the binding and held. The tension is eased and the binding tied in, by twisting it three times with the free end (v). The twists are pulled tight with pliers, the tension reapplied, the tie bedded home with hammer and chisel and binding continued till the sixteenth turn, when the binding is again tied in.

A short length of wire is placed under the twenty-first and subsequent turns (vi). The binding is finished on the twenty-fourth turn and tied in. The wire to the spool is cut, its end flattened, the short length of wire pulled out and the wire with the flattened end inserted in its place, turned back, cut off, and its end hammered well down. The free end is then turned back on its tie and its end hammered down (vii).

Instantaneous couplings have to be prevented from rotating in the adaptor during binding: in the case of the female this is done by a long bolt attached to the adaptor plate, which engages the lug of the coupling; in the case of the male, movement is prevented by leaving the free end of the binding wire attached to the anchoring pin throughout the whole binding process, ties being made with a false tie wire. The final tie is made with this wire, and the binding finished off as before; the free end is then removed from the anchoring pin, cut off, turned over the binding, and hammered down. It should be emphasised that with any form of binding the method of gripping the coupling is important. This is especially so in the case of the male instantaneous coupling described later. As it is liable to distortion it should be gripped from the inside by a device such as an expanding mandrel. On no account should an external vice be employed.

(ii) *Lugless Hose Coupling.* This coupling is used for repairing hose; it also enables short lengths of serviceable used hose to be made into approximately standard lengths. It consists of a pair (Fig. 5, *left*) of (male and female) tails or shanks similar to those of the ordinary hose coupling. In lieu of lugs, solid flanges with four holes for tightening up in conjunction with a "C" spanner are employed. The screw is of the "V" thread pattern and a leather washer is fitted between the flanges to render the joint tight. Once this coupling is installed it is not normally broken. An alternative

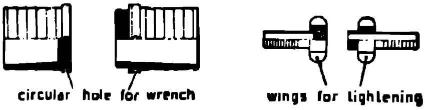


Fig. 5. Left : lugless hose couplings. Right : gas thread first-aid couplings.

method of joining two lengths of hose is to omit the screw portion and to use double tail pieces consisting of a pair of serrated tails with a collar in the middle.

(iii) *Gas-thread Coupling.* This form of coupling, often found on first-aid hose, exists in many types ; Fig. 5, *right*, is representative, and shows a " V "-thread coupling, 12 threads to the inch, for ¾-in. first-aid hose. The male coupling is a metal casting having a serrated tail to which the hose is bound, and a fixed collar with two wings for finger and thumb tightening. The female coupling consists of two castings, a serrated tail ending in an external flange and fibre washer, and a winged nut, internally threaded, moving loosely between the flange and the end of the hose binding. To make the connection, the nut of the female coupling is screwed on to the male by finger and thumb, a final tightening being given by pressure on the collar wings of the male coupling. Small screw couplings for first-aid hose may also be made with holes for tightening with a " C " spanner instead of a wing nut, giving a minimum projection with coiled hose on first-aid reels.

When running out hose with the screw-type coupling, the male coupling is taken to the fire and the female to the pump or water supply.

(*b*) *Interlocking Type Hose Coupling.* There are three main types of this form of coupling : the instantaneous, the " Surelock " or bayonet and the lugged or hermaphrodite, also known as the " Nunan and Stove."

(i) *Instantaneous Coupling.* This is the most extensively used coupling in the Fire Service, being the principal emergency issue and having been in common use by many ex-regular brigades prior to the war.

The principal type of instantaneous coupling fitted to hose issued for emergency appliances (Fig. 6) has double lugs of the standard type, but often types are in use on ex-regular appliances, with pressure release action which still retain their swivelling lugs for running out coils of hose. There is also a type with very short double lugs (giving minimum projection) and pressure release action used on a number of ex-regular appliances where the hose was carried flaked and not in coils.

The female instantaneous half-coupling fitted to all outlets of pumps, standpipes, etc., is of the single lug type, either with or without pressure release action, that adopted for emergency use being fitted with pressure release action. Small instantaneous couplings are frequently used for first-aid outfits and have the advantage that extra lengths of first-aid tubing can be more rapidly added where the original length proves insufficient.

There are two principal methods of securing hose to the double-lug type, the first being employed in couplings of British and the second in couplings of American or Canadian manufacture.

The male coupling of the British type (Fig. 6, i), is a single metal casting with a tail (*a*) which is tied into the hose. The other end of the coupling has a lip (*b*) completely encircling the orifice, with a squared-off tooth edge facing towards the tail to grip the plunger in the female coupling. At the inside end of the tail is a rounded flange (*c*) which assists in making a good joint and protects the opening of the female coupling when the two are married. The interior diameter of the male is constant throughout, apart from the lip orifice, and for a nominal 2½-in. coupling is 2¼ ins. At the lip end the orifice widens out at an angle to a diameter of 2·8 ins.

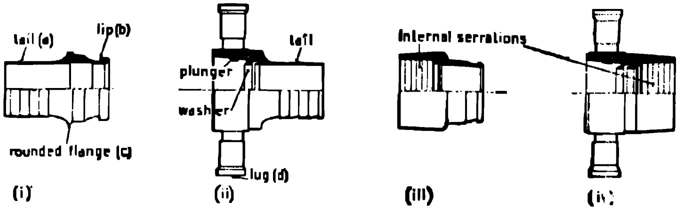
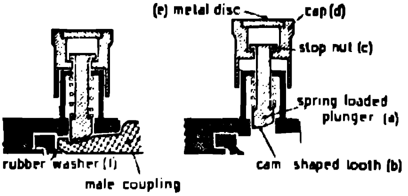


Fig. 6. Instantaneous couplings : (i) British type, male ; (ii) British type, female ; (iii) American type, male ; (iv) American type, female.

The female coupling (Figs. 6, ii, and 7) is a metal casting with a serrated tail similar to that of the male. Two hollow lugs (Fig. 6, ii, (*d*)) are placed in diametrically opposite positions on either side. In each lug (Fig. 7) a spring-loaded plunger (*a*) is fitted, headed on the inside of the coupling with a cam-shaped tooth (*b*) for gripping the lip of the male coupling. The top of the plunger is threaded to take a stop nut (*c*) which holds the cap (*d*) in position. The cap is circular in shape having externally an enlarged knurled rim at the top to give purchase. It is bored out to fit over the lug, which is shaped to form a guide through which the shank of the plunger passes, and by which the spring is retained and the tension governed, leaving the cap free to swivel.



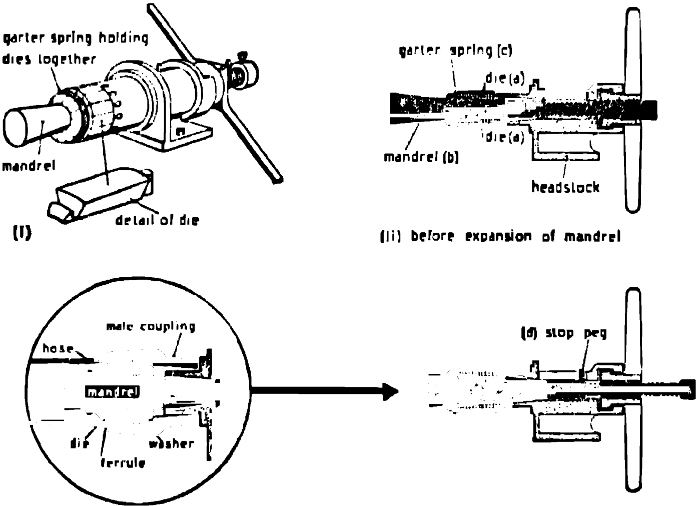
plunger engaged plunger released

Fig. 7. Sketch showing principal parts of a female instantaneous coupling.

A threaded metal disc (*e*) is screwed into the head of the cap to protect the working parts, providing a closed top.

It will be seen that the whole of the assembly is kept in place by the stop-nut, access to which is gained by unscrewing the metal disc in the cap. When hose fitted with instantaneous couplings is run out, the caps which lie over the two lugs of the female coupling at the centre of the roll are grasped and the hose is allowed to rotate. As the cap turns in relation to the lug there is a tendency for the stop-nut to unscrew, but in a well-made coupling this should not occur, since the threads are burred or punched or a grub-screw is employed to prevent this.

The male and female couplings of the American type (Fig. 6, iii and iv) are similar in internal construction and in the method of engagement to the British type described above, but the tail is shorter and is serrated internally instead of externally. The hose, instead of being secured on the outside of the tail by means of wire ties is secured to the inside by means of an expanded metal sleeve or ferrule. A rubber washer is fitted at the far end of the tail, leaving a serrated interior into which the hose is inserted. Before the hose is placed in position an annealed brass sleeve, known as a ferrule, with an external diameter equal to the internal diameter of the hose, is sunk inside the end of the hose so that its end is flush with the hose orifice. The hose is then inserted into the tail of the coupling, and, by means of a special mandrel (Fig. 8, i), known as an expander, the ferrule is enlarged, forcing the hose into the serrations of the tail and thus holding it in position.



(iii) after expansion of mandrel

Fig. 8. Mandrel or expander : (i) general view ; (ii) before expansion ; (iii) after expansion.

To do this (Fig. 8, ii) the ferrule is placed round the dies (*a*) ; the turning of a threaded sleeve draws the mandrel (*b*) towards the handle and expands the dies, which are held in place by a garter spring (*c*) till the stop-peg (*d*) (Fig. 8, iii) comes up against the expander frame at the end of its travel and prevents over-expansion.

An alternative British method of attaching hose to couplings is by means of ferrules. In this method the serrations on the outside of the tail are replaced by a coarse round thread, the overall diameter of which is the same as the internal diameter of the hose. A special ferrule screwed internally with a similar round thread is slipped over the hose, which is then drawn on to the tail of the coupling. The ferrule is then screwed up on the tail of the coupling, its dimensions being such as to force the canvas of the hose firmly into the threads, and thus hold it in position. The ferrule is screwed by means of a special " C " spanner.

The male and female couplings are connected by the insertion of the male, the lip of which presses back the two plungers in the female until they are forced into position behind the rim by the action of the springs. The watertightness of the joint depends on the action of a specially shaped rubber washer (Fig. 7, *f*). The water pressure acting on the washer forces it against the tapered lip of the male coupling and against the seating of the female coupling. Should a leak develop at a coupling due to a faulty washer this can only be remedied by replacing the washer. The couplings are released by seizing the caps on the female lugs and pulling them apart ; this action withdraws the plungers and allows the male coupling to come away.

Under anything greater than a head of a few feet of water these couplings are almost impossible to separate, owing to the pressure acting against the plungers. A charged length of hose, however, can be uncoupled by two men working together. One man grips the hose tightly between his knees, just behind the female coupling ; the other forces the couplings well together, when it will usually be found that the first man can withdraw the lugs. An alternative method is to bend the hose on the supply side of the coupling to as sharp a radius as possible and then kink it to reduce the flow and hence the pressure on the plungers. The lugs may then usually be withdrawn. Occasions have arisen when a man's life has depended upon a quick disconnection being made and, in such emergency, the best action, whatever the type of coupling in use, would be to cut through the hose with an axe as near a coupling as possible.

To permit of couplings being broken under pressure the single and double lug pressure-release types of couplings have been developed. The former type is generally fitted to pump deliveries, breechings and similar fittings.

There are several types of pressure-release couplings. In one type (Fig. 9) there is only one plunger (*a*) which is withdrawn not by means of a direct pull but by the action of a pair of rollers (*b*) running on a cam (*c*). On rotating the cap through part of a revolution the rollers, which are attached to a collar (*d*) on the plunger, rise on the cam and the collar in turn raises the plunger by the stock (*e*) to which it is secured. The spring (*f*), which is mounted on the stock, is compressed at the same time, and returns the plunger into engagement when the cap is released. Another type

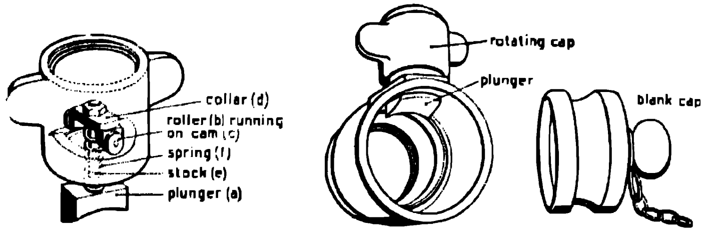
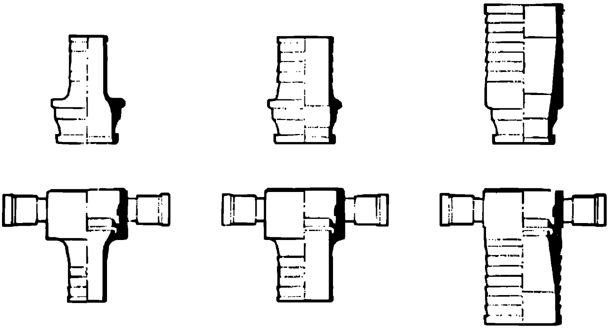


Fig. 9. Sketch showing principal parts of a pressure-release coupling.

has no rollers but comprises two cams acting one against the other; any rotary movement tends to force the cams apart and thus withdraws the plunger. The male coupling is identical with that of the previous type. The chief disadvantage of the single lug coupling is that, having only one point of engagement with the male, it is rather less secure.

In order to permit maximum interchangeability, instantaneous couplings are now made of the same connecting size irrespective of the size of hose. This permits two lengths of hose of differing size to be connected without the use of adaptors. Thus in the standard coupling for use with 3½-in. hose, the tail is enlarged to accommodate the hose, whilst in that for 1¾-in. hose it is proportionately reduced. It should be emphasised that whilst the tails of the couplings are restricted to use with the appropriate size hose, the marrying parts are of one standard and are interchangeable (Fig. 10). Thus a length of 2½-in. hose could be connected at one end to 3½ in. and at the other to 1¾-in. hose by means of the couplings,



(i) 1¾ ins. hose (ii) 2½ ins. hose (iii) 3½ ins. hose

Fig. 10. Instantaneous hose couplings for attachment to hose of different diameters.

without the use of adaptors. It has been found by experiment that the restriction in the bore when using the standard coupling with 3½-in. hose does not cause undue losses.

When running out hose with instantaneous couplings the female coupling is taken to the fire and the male to the pump or hydrant.

(ii) *" Surelock " or Bayonet Coupling.* This coupling, whilst not widely used, is employed in certain branches of the Fire Service such as the ex-regular river service of the former London Fire Brigade, and on radial branches (see later).

The male coupling (Fig. 11, i) is a metal casting with a tail (*a*) having external serrations for attaching the hose by wired ties. Near the other end is a wide flange (*b*), around which are three regularly spaced semicircular indentations (*c*), whilst ¼ in. from the orifice, lying central with the indentations on the flange, are three flat bosses (*d*), each of 1⅞ in. overall length.

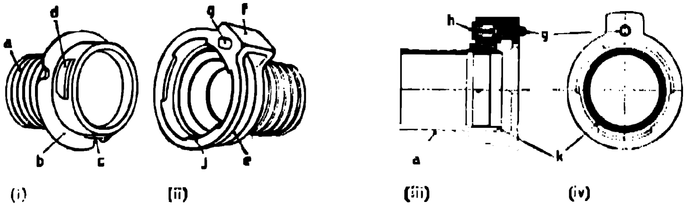


Fig. 11. " Surelock " couplings : (i) male ; (ii, iii and iv) female.

The female coupling (Fig. 11, ii, iii and iv) is a metal casting with a tail similar to that of the male. A heavy collar (*e*), slightly stepped back in two steps towards the tail, is fitted at the non-serrated end. On one side of this collar, formed in the casting, is a squared container (*f*) protruding from the collar. This container has a spring-loaded pin (*g*) running parallel with the coupling and held in position by a holding nut (*h*) with its head towards the shank end. Inside the orifice of the coupling are three equidistant bosses (*j*) and a rubber washer (*k*).

On connecting the couplings the male is inserted in the female so that the internal bosses of the latter engage with the external ones of the former, and the male is turned until the spring-loaded pin is free to move into one of the indentations on the male flange. The couplings are released by pressing the pin in against the spring and giving the male a partial turn.

(iii) *Lugged, Hermaphrodite or " Nunan and Stove " Coupling.* This type of interlocking coupling is used chiefly by the Admiralty and the Merchant Service, and the Fire Service should normally only come into contact with it at docks and on board ships. As its name implies, both parts of the coupling (Fig. 12) are identical, and it is the one case where no reference can be made to the male or female coupling. Each part consists of a metal casting with an external serrated tail (*a*) for wiring on the hose, terminating in a collar slightly over 1 in. in depth. On this collar are two diametrically opposite lugs (*b*), extending beyond the orifice. A squared indentation (*c*) is cut on the inside of this extension to engage two tapering flanges (*d*), each commencing at one lug and ending some 2 ins. short of the other.

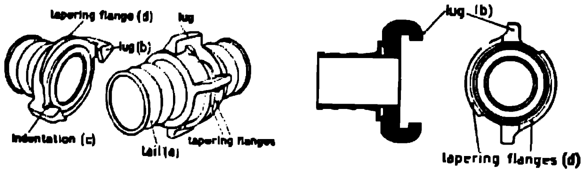


Fig. 12. Hermaphrodite couplings. Left : half-coupling and two half-couplings joined ; Right : section and end view of half-coupling.

To connect hose by means of this coupling, the two parts are put together so that the lugs of each pass through the gaps between the lugs and the flanges on the other. A partial turn of one section then locks the coupling. The chief disadvantage of this coupling is possible leakage and the tendency to work apart, there being no positive grip. The advantage is, of course, that it is immaterial which end of the hose is run out. This coupling was used during the first world war as the basis of a universal adaptor to enable brigades with different hose couplings to work together.

2. SUCTION HOSE COUPLINGS

These couplings are similar in principle to the screw-thread delivery hose coupling. They are made in the following nominal sizes : 1½ ins., 2 ins., 2½ ins., 3 ins., 4 ins., 5½ ins. and 7 ins.

The male coupling (Fig. 13, *left*) has a tail (*a*) with external serrations, two fixed lugs (*b*) and a threaded end (*c*). The thread normally used on suction hose couplings is known as the standard suction round thread and its dimensions have been laid down in British Standard Specification No. 336. This thread has three turns to the inch, the number of turns on a coupling varying between four and six according to the nominal size of the coupling. This type of thread is used on the 2½-in., 3-in., 4-in., 5½-in. and 7-in. couplings. The 1½-in. couplings used on the suction for two-man manuals and the 2-in. couplings used on light portable pumps have " V " threads, and in addition the lengths of 3-in. suction issued for connecting emergency collecting heads to standpipes have been fitted with 2½-in. instantaneous or round-thread couplings. Some variation from the above sizes and threads may also be encountered on ex-regular appliances.

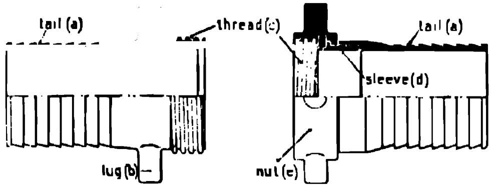


Fig. 13. Suction coupling. Left : male. Right : female.

The female coupling (Fig. 13, ***right***) consists of three castings : tail (*a*), sleeve (*d*) and nut (*e*). These are assembled in the same manner as the female round-thread delivery hose coupling. The nut has four lugs as against the two on the male. The threaded end of the male coupling is slightly enlarged internally to seat against a leather or composition washer in the female.

The threads of suction couplings should be kept lightly greased ; a graphite grease is very suitable, but if rubber washers are employed care must be taken to see that the grease is not allowed to come in contact with them and so cause deterioration.

Since a leak, however small, in suction couplings would allow air to enter and make it impossible to obtain the necessary pressure drop to lift water, particular care in their maintenance is essential. They should never be dropped or roughly handled in such a way as to distort them, and when joined together they must be tightened by using two suction wrenches, one on either coupling. A suction wrench (Fig. 14) consists of a short length of steel bar, about 9 ins. long, one end of which is beaten flat and shaped into a semicircle to fit the size of suction on which it is to be used. An eye is provided at the shaped end for engaging the lugs of the couplings, and care should be taken to use the wrench in the correct way, so that its curve follows the coupling. Four sizes of suction wrench have been issued with emergency appliances, 3 ins., 4 ins., 5½ ins., and 7 ins.

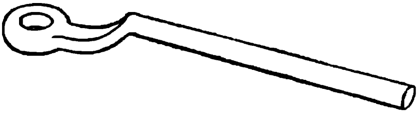


Fig. 14. Suction wrench.

ADAPTORS

Adaptors are fittings made for the purpose of connecting hose or suction couplings of different types or sizes or for connecting the male to male or female to female parts of the same type of coupling.

They consist of a metal fitting terminating at each end in a coupling and average between 4 and 6 ins. in length.

Adaptors are usually cast as one fitting, except in the case of screwed female ends where the nut and sleeve are separate.

1. DELIVERY HOSE ADAPTORS

The following types are in general use :—

(*a*) Adaptors for connecting male or female parts of the same type of coupling :

Male to male Female to female	Round thread, " V " thread or instantaneous.

(*b*) Adaptors for connecting two different types of coupling :

Male to male Female to female	Round thread to instantaneous (Fig. 15, *left* and *centre*). Round thread to Surelock, " V " thread to instantaneous.
Male to female	Round thread to " V " thread.

As an emergency measure, adaptors for connecting screw thread to instantaneous hose have been made by tying two hose couplings of the required type one into either end of a 9-in. piece of hose. Special adaptors for connecting into the delivery and into the suction line of a pump are also used with a multiple jet inductor for the larger size foam - making branches. These are dealt with in the Chapter on "Foam and Foam-making Branches."

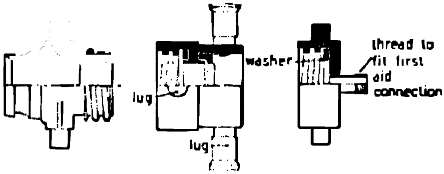


Fig. 15. Adaptors. Left: round thread male to instantaneous male. Centre: round thread female to instantaneous female. Right: round thread female to gas (first-aid) thread.

2. HYDRANT ADAPTORS

These adaptors are used between the base of the standpipe and the hydrant outlet, and may be of the same pattern as delivery hose adaptors, though other combinations of thread or connection, such as female bayonet to female instantaneous, female round thread to lugged, or lugged to male " V " thread, will also be found.

3. FIRST-AID ADAPTORS

The first-aid adaptor (Fig. 15, *right*) is used to connect first-aid tubing direct to a hydrant or to a length of delivery hose. It consists of a metal casting fitted with a female round or " V " thread or male instantaneous coupling for attachment to the hose or hydrant outlet, and a gas thread connection or instantaneous first-aid size female coupling to connect to the first-aid tubing.

4. SUCTION ADAPTORS

These are used for connecting delivery hose to hard suction or to the pump inlet or to join lengths of suction of differing diameters.

(*a*) *Metal Castings.* Suction adaptors normally consist of a metal casting with either a male suction coupling and a female instantaneous (Fig. 16, i) or male screw coupling (iii), to take the

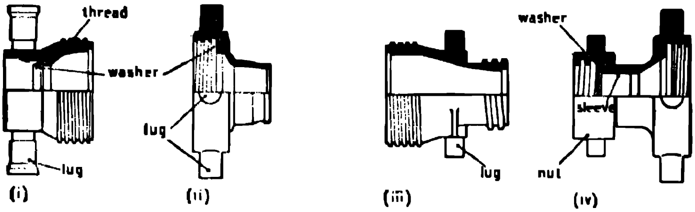


Fig. 16. Suction adaptors: (i) male suction to female instantaneous delivery; (ii) female suction to male instantaneous delivery; (iii) male suction to male round thread delivery; (iv) female suction to female round thread delivery.

hose or a standard female suction coupling with a male instantaneous (ii), or female round-thread coupling (iv) at the other end.

Adaptors for connecting suction of differing diameters usually have a female connection at one end and a male at the other.

(b) *Suction Reduction Piece.* This consists of a short length of suction hose from 3 to 6 ft. in length, smaller in diameter than the main suction, with an appropriate hose coupling at one end for attachment to a standpipe head, and a female suction coupling at the other for union with the main suction hose or the pump inlet.

BREECHINGS AND MISCELLANEOUS FITTINGS

Breechings, generally speaking, are used for two purposes ; for uniting two lines of hose into one (known as a collecting breeching), or for dividing one line into two (known as a dividing breeching). There are also special breechings, such as suction breechings, which bring two or more suctions to a common inlet.

I. COLLECTING BREECHINGS

Collecting breechings may be of two principal types (*a*) where the two inlets and the outlet are all designed to connect to hose of the same diameter, and (*b*) where the two inlets are designed to take hose of one diameter and the outlet that of another diameter.

(*a*) The simplest form of collecting breeching is shaped like a " Y " (Fig. 17, *left* and *centre*). Each of the two legs is fitted with a female coupling, if the breeching is for screwed couplings, or a male coupling if for instantaneous hose. The single coupling on the stem of the " Y " is male, if screwed, and female if instantaneous : in the latter case a single-lug pressure-release coupling is used. A control collecting breeching similar in construction to the control dividing breeching shown in Fig. 18, *right*, may also be encountered. This is illustrated in Fig. 33. Breechings are normally made of gun-metal, brass or bronze.

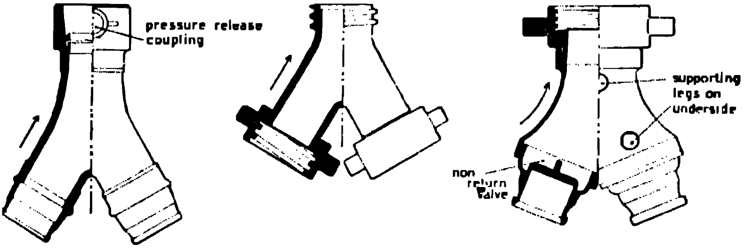


Fig. 17. Collecting breechings. Left : instantaneous couplings. Centre : round thread couplings. Right : breeching for use with a deluge set.

(*b*) The collecting breeching for use with a large branch, such as a radial branch or deluge set, differs somewhat owing to the use of a short length of 3½-in. hose as a feeder. Breechings for this purpose have an outlet coupling of the 3½-in. " Surelock " or V thread type and inlet couplings to suit round thread or instantaneous hose.

A typical example is illustrated in Fig. 17, *right*. The supporting legs on the underside are fitted to ensure that the breeching is placed on the ground in the correct position. If it were placed upside down the flap-type non-return valves would not operate.

(c) The suction breeching, which is now being superseded by the collecting head (see later), consists of a " Y "-shaped gunmetal brass or bronze casting fitted with a standard female suction coupling at one end for attachment to the suction inlet of a pump and dividing at the other end into two legs, each fitted with the appropriate coupling for connecting delivery hose. The function of the breeching in the case of a pump with one inlet is to gather water from two different sources. In the case of a pump equipped with two inlets, the suction breeching is attached to one inlet, the second being either blanked off or connected to the suction hose.

This breeching is unsatisfactory for use when relaying. The absence of non-return valves results in the possibility of reverse flow occurring when twin lines of hose connected to the breeching are working at unequal pressures.

2. DIVIDING BREECHINGS

These breechings are principally used to divide a line of hose under good pressure into two lines, so that two branches may be used, particularly when cooling down. Such a breeching is often used to feed two 1¾-in. lines of hose from one 2½-in. or 2¾-in. line, a good example of the value of having a standard size coupling. This breeching, if for instantaneous hose (Fig. 18, *left*), would consist of a male inlet and two female (pressure release) outlets, whilst for screwed hose couplings (Fig. 18, *centre*) the breeching would possess a female inlet and two male outlets.

A specialised form of dividing breeching is the " control dividing breeching." In this the two outlets and the inlet are controlled by a valve (Fig. 18, *right*) which can be rotated to shut off either or both legs. The position of the control handle for the various operating

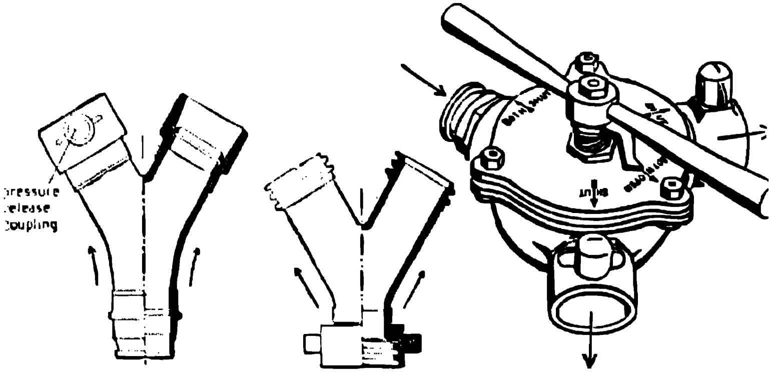


Fig. 18. Dividing breechings. Left : instantaneous couplings Centre : round thread couplings. Right : control breeching.

positions varies with different models, but is usually clearly marked on the breeching itself. The advantage of this breeching is that either hose line can be shut off without closing down the other and lengths can be added or removed as desired. The exact position of the valve varies with different models, and these breechings are also found having a separate valve on each of the legs.

These breechings are of particular value when fighting heath and similar fires where long hose lines are in use and water is extremely scarce.

3. ANGLE FITTING

This is a right-angled metal casting fitted with a coupling at either end. It is used on the outlet of a pump or for insertion between the two halves of a coupling in order to change the direction of a line of hose in a confined space without kinking.

4. BLANK CAP

A metal casting (see Fig. 9, *right*) used for shutting off an inlet or an outlet such as the delivery on a pump or the inlet on a collecting head. Larger blank caps are made to shut off the suction inlet on a pump.

BRANCHES, NOZZLES AND BRANCH-HOLDERS

The branch-pipe, or branch as it is now generally called, is used at the delivery end of a line of hose to increase the velocity of the water and so yield an effective firefighting jet. The size of the jet is governed by the nozzle, which screws on to the outlet end of the branch. In the earliest examples, branch and nozzle were in one piece.

The branch consists of a metal tube having an interior diameter which reduces gradually in size towards the delivery end. The reduction in area is further continued in the nozzle until at the orifice the diameter measurement is that by which the nozzle and jet are known.

Recently, in an endeavour to reduce the weight of these fittings and to economise in metal, experiments have been made with plastic mouldings incorporating a metal nozzle. These experiments have so far proved inconclusive.

1. BRANCHES

Branches may be divided into two principal classes :

(*a*) Those that yield a fire stream in the form of a jet which cannot be controlled by the branch operator.

(*b*) Those that provide for some form of control by shutting off the jet, altering its shape or size, or changing its character, *e.g.*, converting it into a spray.

(a) Branches and Nozzles giving a Jet not Controlled by the Operator

(i) *" Ex-regular " Branches.* These are usually of copper, fitted with either a round or " V " thread female or a male instantaneous coupling at one end to fit the hose and a male " V " thread or small round-thread connection at the other to take the nozzle (Fig. 19). The interior of the branch is free from obstruction.

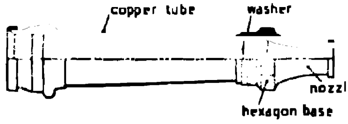


Fig. 19. Typical long branch

The length of these branches varies considerably. In the nineteenth century branches were often as much as 6 ft. long, and those with a length of 2 to 4 ft. are still found, especially in factories, hotels and other similar premises, often of an antiquated design. To keep the weight within reasonable limits a long branch is necessarily of light construction and consequently is easily damaged.

Modern types are from 1 ft. to 1 ft. 6 ins. long. The delivery orifice, over which the nozzle screws, has a diameter of 1·75 ins. for nozzles up to 1·5 ins., and a second type has a diameter at the orifice of 1·5 ins. for nozzles up to 1·25 ins. A washer, usually of leather, is used for making a tight joint between branch and nozzle. These types are sometimes known as long branches.

Leather and rubber branches are sometimes met with: it is claimed that they are lighter and easier to handle in cold weather.

(ii) *Emergency Branches.* As understanding has increased of what happens in the branch, the length has been progressively reduced: the emergency branch, sometimes known as the short branch, which has been issued in large numbers, is only 8 ins. in overall length for the round- or " V " thread type (Fig. 20, *left*), or 8·25 ins. for the instantaneous type (Fig. 20, *right*).

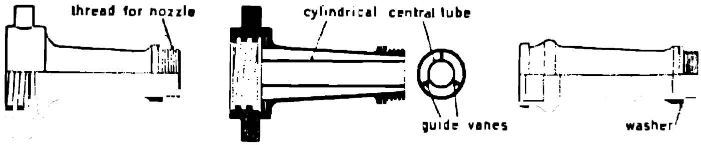


Fig. 20. Short branches. Left : round thread. Centre : streamform. Right : instantaneous.

It consists of a solid brass casting, the approximate weight of which is 4½ lbs. for the threaded type, and 3 lbs. 10 ozs. for the instantaneous type. Owing to its robust construction it will stand rough treatment that would severely damage a long branch.

(iii) *Streamform Branches.* The streamform branch (Fig. 20, *centre*) is similar to the short branch in outward appearance, but internally is fitted throughout its whole length with a cylindrical central tube open at both ends and of 1 in. diameter, held in position by three longitudinal guide vanes. The advantage claimed for this branch over the long or short types is that it gives a more solid jet. This is based on the theory that the speed of water flowing in hose is greater in the centre than at the boundary where there is friction with the wall. As the cross-sectional area of the central tube does not diminish, the velocity of that part of the water which travels through the tube must be the same at the end as at the beginning. The velocity of the slower moving water in contact with the walls of the hose is greatly increased in the branch owing to its taper and, on reaching the nozzle, is actually travelling faster than the water leaving the central tube. Thus the jet is composed of a central core held together by a faster moving outer sheath of water, which tends to drag the core along with it, the friction of the particles holding the whole together and giving a solid jet. This branch is usually of much the same length as the short branch. Some manufacturers have made a longer model, but there are few of these in general use.

The streamform branch is not a standard issue but is carried on many ex-regular appliances.

(iv) *Twin or Siamese Branches.* In order to deal with greater quantities of water than is possible with a branch fed by a single line of hose, twin branches have been employed in some localities. These consist of a relatively long branch which bifurcates at the lower end, each leg terminating in a coupling for attachment to a line of delivery hose. The branch is thus fed by twin lines of hose. Owing to the greatly increased reaction of the larger nozzle which can be employed and the added weight of the twin hose line, a simple form of holder is employed.

(v) *Extended Branches.* These are sometimes used at grain, coal, haystack and similar fires.

They are found in varying lengths and sizes, many of them having been made up locally from copper, brass or other metals to suit particular requirements. Branches for dealing with fires in coal stacks and bunkers, for example, are usually some 10 ft. in length and constructed from steel. A typical example consists of a 10-ft. length of 2½-in. steel piping having at one end a pointed head which is pierced with a number of ⅛-in. holes and at the other a thread on which may be screwed either a collar containing a standard hose coupling or another 10-ft. section of piping to extend the branch still further. A driving head may also be screwed on to this thread to enable the branch to be driven into the stack or bunker, after which the head is withdrawn and the coupling screwed on so that hose can be connected.

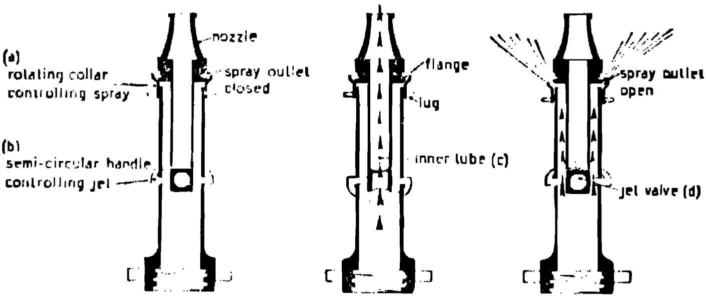
In some localities smaller branches often from 2 to 3 ft. in length and of less than 2½ ins. diameter are used, particularly for dealing with fires in hayricks. A sliding adjustable collar is sometimes provided on such branches by means of which the angle at which the water is emitted into the stack can be varied.

(b) Branches which can be Controlled by the Branchman

(i) *The Hand-controlled Branch.* This branch, also known as the " London " branch (Fig. 21), is most useful for small fires and forms part of the equipment of the majority of ex-regular pumps and pump escapes. With it either a jet or a spray or both can be obtained, each being independently controllable by the branchman. The spray may be adjusted to any desired angle as circumstances require and may be used as a protection against heat and smoke, whilst at the same time a solid jet is available with which to attack the heart of the fire. As both jet and spray can be shut off at will, the branch is valuable as it minimises water damage, whilst the spray is also useful for turning over and cooling down purposes. This type of branch should not ordinarily be used with a pump since at normal pump pressure injudicious use of the shut-off may result in burst lengths of hose, damage to the pump and danger to the operator and men working on other lines of hose.

The branch consists of 14 metal parts including screws and detachable nozzle. The main casting is made of aluminium, 12 ins. in length, with a fixed female round- or "V" thread or a male instantaneous coupling at one end for connecting to the hose. The casting is tubular in shape and, apart from the coupling, is cylindrical throughout its whole length.

Below the base of the nozzle is a rotating collar (*a*), fitted with lugs, which controls the spray; and approximately halfway down the casting a semicircular handle (*b*) controls the jet. In its essentials the hand-controlled branch consists of an inner tube (*c*) communicating direct with the nozzle, governed by a jet valve (*d*) operated by the semicircular handle, and the annular space between the inner tube and the main casting communicating with the spray outlet, which is opened or closed by rotating the movable collar on a screw thread, the adjustment of which controls the angle of the spray.



both jet & spray shut jet open: spray shut jet shut: spray open

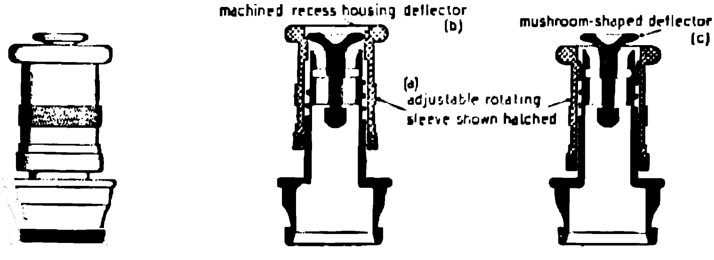
Fig. 21. Hand-controlled branch. Left: jet and spray shut. Centre: jet open, spray shut. Right: jet shut, spray open.

The action of the hand-controlled branch is as follows: The water from the hose enters into the main casting of the branch; if the jet valve handle is in its forward position (Fig. 21, *left*) the entrance to the inner tube is closed; if the handle is pulled back (Fig. 21, *centre*), the bore in the valve allows the water to pass through into the tube and so to the nozzle from which it discharges in jet form. The nozzle is screwed to the branch in the ordinary way and can be replaced by nozzles of other sizes as desired. Normally a ⅝-in. or ¾-in. nozzle is employed but smaller sizes can be used according to requirements. The internal dimensions of the branch do not permit the use of nozzles larger than ⅞ in. nor would their employment be wise in view of the use of a shut-off valve. Entirely independently of the jet valve, water from the hose by-passes it and continues along between the inside wall of the main casting and the outside of the inner tube, into an inner sleeve, and emerging through a series of oblong holes in the latter into the main casting. (Early models of this branch have a bulge formed in the main casting at this point. This bulge has now been abandoned.) The water continues until it hits a flange on the branch outlet piece. Its further passage is controlled by means of the lugged collar. If this collar is turned on its thread in a clockwise direction (when looking towards the jet) it presses tightly against the flange on the branch outlet and the water can flow no further. If it is turned anticlockwise (Fig. 21, *right*) a gap is created and the water flows out in the form of spray, the angle of which is controlled by the amount of turning given to the collar, in other words according to the size of the gap. The spray can be varied from a cone of about 30 to 40 deg. to a flat sheet of 180 deg.

When changing over from jet to spray it is important to see that the spray is turned on *before* the shut-off controlling the jet is operated.

(ii) *Diffuser Branch.* There are several classes of fire which can be dealt with more satisfactorily by the use of water in a diffused form than by the usual straight jet or fire stream. Included in these are fires involving inflammable liquids, *e.g.*, varnish or small quantities of petrol. Fires in premises containing inflammable materials of a light nature can also be effectively dealt with by this method, provided that the diffused water can be used at close range.

The diffuser branch supplied for emergency use (Fig. 22, *left*) has the advantage of providing by adjustment either a good fire stream or a finely diffused spray. The spray can be controlled and has a wide range varying from an intense mist over an angle of 180 deg.


machined recess housing deflector
(b)
mushroom-shaped deflector
(c)
(a)
adjustable rotating sleeve shown hatched

diffuser branch

branch fully closed

branch fully open giving 180 deg. spray

Fig. 22. Emergency type diffuser branch. Left : general view. Centre : sectional view, fully closed. Right : sectional view, fully open.

(Fig. 22, *right*) to a complete shut-off (Fig. 22, *centre*), and the operator can judge by experience the best adjustment for the type of fire concerned.

For smoke driving, or for cooling the atmosphere in a room, the best adjustment is when the spray forms an angle of about 90 degs. If a liquid fire is to be attacked, the angle of the spray should be closed down to about 30 degs. to give a very dense or concentrated spray. This type of spray is also very useful for attacking fires of ordinary free-burning material at close quarters, *e.g.*, inside a room.

If circumstances prevent close approach to the fire, the spray angle can be closed down until a moderately good fire stream or straight jet is produced, and for small fires where the use of large quantities of water is undesirable, or where only a small quantity of water is available, the jet can be reduced still further until it is comparable with the small jet in the first-aid apparatus used on appliances.

It has been found by experiment that the best results are obtained if the pressure at the base of the branch is maintained at 80 to 100 lbs. per sq. in., although quite good results are obtainable with pressures as low as 50 lbs. per sq. in.

The amount of water discharged in g.p.m. at various adjustments through the diffuser branch issued for emergency purposes is given in Table I :—

TABLE I

Pressure in lbs. per sq. in.	G.P.M.			
	Wide spray 90 deg.	Narrow spray 30 deg.	Fire Stream	First-Aid Stream.
100	140	120	65	9 to 15 g.p.m.
90	135	110	50	
80	130	101	40	
70	122	92	32	
60	115	86	24	
50	98	75	18	
40	90	65	—	

Special care must be taken to ensure that there is no obstruction in the orifice between the deflector and the nozzle, otherwise poor streams or spray will result. Branches should be examined after use and any obstruction removed.

The construction of the branch is shown in Fig. 22. It consists of a main body in which is rigidly mounted a mushroom-shaped deflector and a male instantaneous coupling for connection to the hose. A rotating sleeve (*a*) with a milled grip travels in a coarse thread screw. At the forward end of the sleeve is a machined recess (*b*) somewhat wider in diameter than the head of the deflector (*c*). As the sleeve is moved forward this recess envelops the head of the deflector, leaving an annular opening which is gradually reduced as the sleeve moves forward, until it is closed off when the sleeve reaches the full extent of its travel. When the sleeve is fully withdrawn a flat spray (180 deg.) is produced, whilst as it is moved forward the angle of spray is progressively reduced owing to the directing effect of the recess.

2. NOZZLES

(a) Standard Nozzles. Standard nozzles to fit any of the branches used with 2½ and 2¾ in. hose are made of machined gunmetal or brass, and vary in overall length from 4 to 4½ ins. Standard nozzles are fitted with a female connection for attachment to the branch and may be of " V " thread or a round-thread of five threads to the inch (Fig. 23).

The " V " thread is the more common and is now standard except for replacements for existing equipment. The interior of the nozzle at the branch end is of the same bore as the internal diameter of the delivery orifice of the branch and continues so for a short distance, when it gradually tapers off to the required bore by which the nozzle is named. As a precaution against damage, the delivery orifice is countersunk in the nozzle to a depth of ⅛ in. The nozzle has a large rim as a further protection. At the branch end the nozzle is hexagonal to permit of the use of a special spanner for coupling or uncoupling. The nozzle spanner consists of a simple forging which may be combined with a hose spanner (Fig. 3) where screwed couplings are in use.

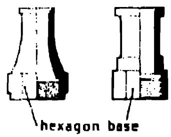


Fig. 23. Nozzles. Left : emergency pattern with " V " thread connection. Right : nozzle for branch with round thread connection

These nozzles are made with the following delivery bores by which they are known : 3/16 in., ¼ in., 5/16 in., ⅜ in., ½ in., ⅝ in., ¾ in., ⅞ in., 1 in., 1⅛ in., 1¼ in., 1⅜ in., 1½ in., 1⅝ in., 1¾ in., 2 ins., and occasional larger sizes. The 3/16-in. nozzle is generally used in place of the first-aid outfit in conjunction with 1¾-in. hose, whilst nozzles from 1½ in. upwards are used on radial branches, deluge sets and monitors. Nozzles for deluge sets or monitors range in size in this country up to 3½ ins., but a fireboat of the New York Fire Department has a monitor fitted with a 5-in. nozzle. Generally speaking, any nozzle over 1½ in. has a connection to take a special branch outlet of a larger size than that of the standard long or short branches, *e.g.*, as on a monitor.

The " working nozzle " is an expression used for the nozzle on the branch kept permanently coupled to the first line of hose to be got to work at a fire. Working nozzles vary in size throughout the country as they are determined by local preference, the availability of water, and by the capacity of the pump.

Nozzles should be subjected to frequent inspection, special care being taken in looking for scratches or indentations and in checking that the inside section is truly circular. The orifice itself should be knife-edged. The smallest defect or the absence of a highly polished surface will result in a broken jet. Nozzles should not be tightened on to the branch with excessive force, or the washer, usually of leather, is distorted and a leaking joint may ensue.

(b) First-aid Nozzles. These are nozzles usually of a very simple pattern resembling a large pet-cock (Fig. 24) in which the jet can be turned on and off by means of the rotating plug. In the majority of these nozzles the handle lies at right angles to the nozzle in the " off " and is pushed forward to the " on " position. The nozzle is attached to the first-aid tubing by means of a female " V " threaded connection (12 threads to the inch) which is screwed on to a lugless male connection on the tubing.

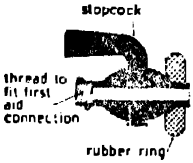


Fig. 24. Section of first-aid nozzle, showing rubber ring to protect it from damage.

There are, however, various other types of first-aid nozzles, such as those where the nozzle is part of the body of the pet-cock, having a female screw inlet or a male instantaneous inlet, or, again, a detachable nozzle. In another type in which the pet-cock has a serrated tail for wiring direct to the hose, it may also have a detachable nozzle. All the above types may have on the outlet side of the cock a female instantaneous first-aid size coupling to take a detachable nozzle having an instantaneous male inlet. This is frequently used and is designed so that in place of the nozzle a further length of hose can be connected.

The usual size first-aid nozzle is $\frac{3}{16}$-in. bore and 4 to 5 ins. in length. A ring of rubber is frequently fitted around the base to lessen the chances of damage.

(c) *Shut-off (First-aid Type) Nozzle for 2¾-in. Hose.* This nozzle, similar in action to the first-aid nozzle, is coupled directly to hose fitted with round-thread couplings. Nozzles of this type were issued on a restricted local basis to self-propelled heavy units pending the receipt of diffuser branches. Such nozzles, which are $\frac{3}{16}$-in. diameter, can best be used from a low-pressure hydrant and create as little damage as would a genuine first-aid outfit.

(d) *Small Nozzles.* A large variety of small nozzles are in use for hand pumps, stirrup pumps and chemical extinguishers. These nozzles are either designed for a jet, with or without a control cock, or are of a double-acting nature such as the thumb-operated nozzle of the stirrup pump. The stirrup-pump nozzle is intended for use as a jet or spray and the changeover from one to the other is obtained by a metal slide containing a round hole for the jet and an oval slit for the spray, which can be pushed across the orifice of the nozzle by means of the thumb. The dual nozzle is, however, now being discontinued in favour of a nozzle giving a jet only.

(e) *Miscellaneous Nozzles.* A great number of uncommon nozzles were in use by ex-regular brigades, some of general manufacture, and others made up locally. Amongst these may be grouped nozzles giving a jet which can be adjusted to any size from shut-off to 1 in., various types of spreading nozzle and fan spreaders, globe spreaders, rose nozzles and a wide range of spray nozzles and general spreaders for washing down or cooling down purposes.

(f) *Basement Spray.* In place of a nozzle for producing a solid jet, what is known as a basement spray (Fig. 25) may, for special purposes, be connected to the branch. This is a gunmetal fitting with a suitable thread for attachment to a branch having on the lower end a fork to which is bolted, at right angles to the branch orifice, a deflector plate so constructed as to throw a spray of water in all directions like a sprinkler head. This spray is used for dealing with fires in basements and ships' holds, where an all-round cooling effect is required. If the branch is of the screwed coupling type the basement spray and branch should be lashed to the hose coupling by means of a belt line, which is normally kept permanently fastened to the spray. The impact of the water on the deflector has a tendency to cause the whole spray to unscrew off the branch.

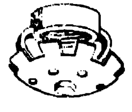


Fig. 25. Basement spray for connection to a branch.

(*g*) ***Elbow-for-nozzle.*** This is a metal attachment (Fig. 26) which can be fitted between the branch and the nozzle so as to enable a jet of water to be delivered at right angles to the branch. This extension to the branch is used for attacking fires in a basement or ship's hold, when, owing to the density of the smoke or for any other reason, it is impossible to get down to the fire.

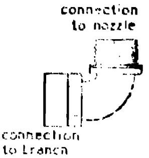


Fig. 26. Elbow-for-nozzle.

3. SPECIAL TYPES OF BRANCH

In addition to the long, short or diffuser branches, a number of specialised forms of branch for dealing with particular kinds of fires have been developed.

(*a*) ***Two-way Branch.*** This is a gunmetal casting (Fig. 27) fitted with a female round-thread or male instantaneous coupling at one end for attaching to a line of hose, with the other end terminating in two nozzles in line opposite to each other, and at right angles to the line of hose. One nozzle is threaded and is fitted with a blank cap so that the branch may be used in place of an elbow-for-nozzle. This branch is used for certain basement fires when working through a hole in the floor above, and is useful for attacking fires under platforms and the decks of ships, wharves, etc. It is not intended to revolve, but on a screwed coupling it is liable to unscrew and consequently should be lashed by means of the belt line to the lugs of the hose coupling. The nozzles are tilted slightly upwards and the non-threaded nozzle possesses a large rim to protect the orifice. If the threaded outlet is required the blank cap is removed and a standard nozzle is screwed on in place of it.

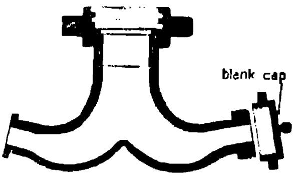


Fig. 27. Two-way branch having at left nozzle, and at right threads for attachment of a second nozzle or a blank cap as required.

(*b*) ***Revolving Cellar Nozzle.*** This piece of equipment consists of a female round-thread or male instantaneous coupling carrying a semi-spherical metal casting which is able to revolve on it freely in a plane at right angles to the coupling. Fitted to this casting are four $\frac{7}{16}$-in. nozzles at right angles to the hose. Each nozzle is inclined at an angle of 45 degs. to the diameter. Two diametrically opposite nozzles throw jets in the plane of revolution whilst, of the other two, one is turned slightly upward and the other slightly downward. As water passes through the branch under pressure the latter revolves, throwing out a curtain of water in all directions. The revolving cellar nozzle is mainly used for lowering into basements and ships' holds.

(*c*) *Double Revolving Branch.* This consists of a large gun-metal casting made in two parts (Fig. 28). The upper part comprises a collecting breeching providing connections for two lines of hose which support the weight of the casting when in use. The lower section, which revolves on ball bearings, is fitted with four equidistant outlets. Two of these (diametrically opposite) are in the form of branches to which ordinary standard nozzles may be attached. The other two outlets, also located opposite to each other, are inclined to the diameter. The slanting streams of water issuing from these two outlets develop the back pressure which revolves the lower part of the casting. When getting a double revolving branch to work, the branch should be lowered into position by using the two lengths of hose only ; a line should not be attached. Other types have a single instantaneous inlet fitted with two jets for rotation and with two streamform branches to project the water, or three nozzles set at different angles which serve for both rotation and firefighting. This branch is for use in ships' holds and for basements where large quantities of water spread over a considerable distance are required. A more compact piece of apparatus is a revolving nozzle, usually attached to a branch, with nine or more openings set at different angles, both for rotation and spreading, the whole running on ball bearings, and compact enough to be lowered down a ship's ventilator or a small hole cut in a floor.

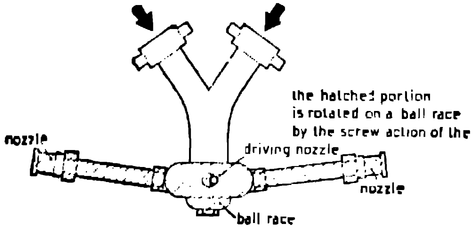


Fig. 28. Double revolving branch.

(*d*) *Cellar Pipe.* This piece of equipment (Fig. 29) is used at smoky fires in basements and ships' holds and is actuated through a deadlight or hole cut in the floor. It consists of a metal tube or pipe of 2¾ in. bore with a right-angle bend in the middle, jointed towards the end of the first part so that it may be folded when not in use. The total length is about 4 ft. 6 ins. The first section of the pipe has a coupling (*a*) at one end for direct attachment to a length of hose; approximately 12 ins. from this coupling a foot iron (*b*) is attached to the pipe by means of a metal collar. This is used to steady the branch when in use. Three inches beyond the foot iron the pipe is slightly enlarged to form a chamber containing a command valve (*c*) operated by an external handle similar to that on a household tap. This first section terminates in a flanged lip (*d*) and forms a section of the hinge on which the pipe is folded when not in use. The second section commences with a flanged lip with snap fastener at the top to complete the hinge, and a right-angled elbow. Slightly below the bend is fitted a diffuser collar (*e*) which, when the pipe is in use, permits water to emerge in a cone of spray, forming a curtain to hold back thick smoke from the operator. The pipe terminates some 2 ft. from this diffuser collar in a base (*f*) which can be rotated by a control handle (*g*) attached to a metal rod some 2 ft. 9 ins. in length, which emerges through a stuffing box in the elbow. To the rotating base is attached at right angles a swivel-jointed nozzle (*h*), the inclination of which can be adjusted by means of the control handle. Thus, when the latter is turned, the rotating base turns with it, swinging the nozzle around in any direction. If the handle is raised or depressed, the nozzle on its swivel is directed downwards or upwards respectively.

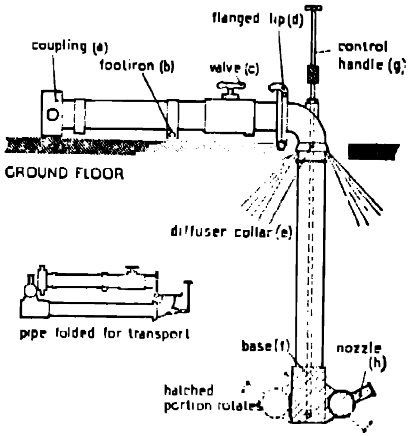


Fig. 29. Cellar pipe.

(e) *Gooseneck.* The gooseneck or swan-neck (Fig. 30) consists of a short length of pipe curved in a semicircle and fitted with a coupling at one end for attachment to a line of hose in place of a branch. The bore of the gooseneck remains constant throughout and is approximately that of the hose. The length of pipe from coupling to the outlet is about 2 ft. It is designed for use when filling emergency water supply dams and tanks as it can be hooked over the side and obviates the otherwise necessary lashing of the hose coupling and the sharp bending of hose across the end of the tank. In some localities the gooseneck is found permanently attached to the tank.

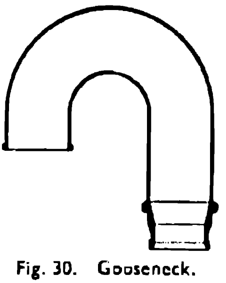


Fig. 30. Gooseneck.

(*f*) ***Radial branch.*** The radial branch (Fig. 31) is designed to direct larger jets than can ordinarily be handled normally and is used with nozzles up to 2 ins. diameter (Fig. 31, ***inset***). The branch holder consists of two double stays, one (*a*) of 4 ft. 6 ins. in length, pointed at the bottom end to give a purchase on the ground to the front, and the other (*b*) of 3 ft. 6 ins. fitted with a steel-studded plate (*c*) which also rests on the ground to the rear: the double rear stay carries at the upper end a branch (*d*) fitted with a 3½-in. " Surelock " coupling (*e*) for connection to 3½-in. hose (*f*). This stay, which is hinged on the base plate, slides up and down on the double front stay which acts as a guide. The movement is controlled by a simple winch gear (*g*) carried at the head of the front stay which controls the elevation of the jet. A locking screw (*h*) on the sliding carriage is provided to clamp the branch in position and thus take the weight off the cable (*i*) and winch gear. Above the winch gear is a handle (*j*) used by the branchman to control the branch.

When working with the larger size nozzles (*k*) and under high pressure the radial branch requires considerable quantities of water and twin lines of hose are necessary to supply it.

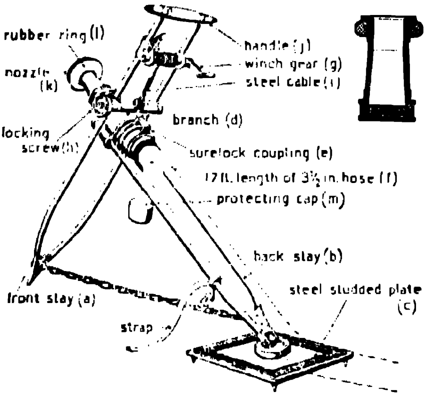


Fig. 31. Radial branch : (*inset*) typical radial branch nozzle.

The branch is fed by a 17-ft. length of 3½-in. hose, usually rubber-lined, fitted with " Surelock " couplings. The hose rests on the rear stay when charged. A special form of breeching (already described) with twin inlets for the 2¼-in. or 2¾-in. hose and a single 3½-in. " Surelock " coupling outlet is used to feed the 3½-in. hose.

When using the branch the operator stands on the base plate straddling the hose. The inclination of the jet is varied by means of the winch gear, whilst the direction can be altered within limits by pivoting the branch about the base plate. A cardinal rule for operation is, however, that the feeder hose shall be approximately in line with the direction of the jet. Owing to the size of the jet a radial branch can fairly easily pass out of control and is then extremely dangerous. The nozzles used (***inset***) range from 1¼ ins. to 2 ins. diameter and are usually fitted with a rubber ring (*l*) to protect them from damage. A nozzle protecting cap (*m*) is also issued with each branch as an additional precaution.

4. MONITORS

When it is desirable to economise in man-power and leave a jet at work unattended, or to place a jet in a position of danger, as, for instance, when there is risk of falling walls, or when very large quantities of water are required under high pressure, equipment known under the general heading of a monitor is employed. Constructional details of monitors vary considerably but they may be divided into two principal classes :

(*a*) Those designed to work on land and which may be carried to the place where the jet is to be got to work.

(*b*) Those which are permanently secured to an appliance, which is usually a fireboat, but which may be a land appliance such as a pump or a pump-escape.

(*a*) *Movable Monitors.* Since monitors require large quantities of water they are almost invariably fed through twin lines of hose which connect either direct into a breeching on the monitor or into a breeching and through a short length of 3½-in. hose.

(i) *Deluge Set.* One of the simplest forms of monitor is the deluge set issued under the emergency scheme The deluge set (Fig. 32, *right*) consists of a branch and nozzle mounted on the frame of a collapsible 100-gallon dam (Fig. 32, *top left*). The branch (*a*) can be either elevated (*b*) or traversed (*c*) by means of quadrant gears actuated by handles, and is provided with a small hole (*d*) through which water passes to maintain the water level in the dam (*e*). The dam, when filled with water, acts as an anchor to overcome the back pressure set up by the fire stream issuing from the nozzle (*f*). Care must be taken to have the dam completely filled before putting any pressure on the branch. Water is supplied from the pumping units to a collecting breeching which is connected to the base of the branch on the deluge set by means of 20 ft. of 3½-in. hose (*g*). The nozzles supplied with this set are of 2½-in., 2-in. and 1¾-in. diameter. The set can be used either ashore, where a large fire stream is required, or on board a fireboat as a monitor. Once set up in the

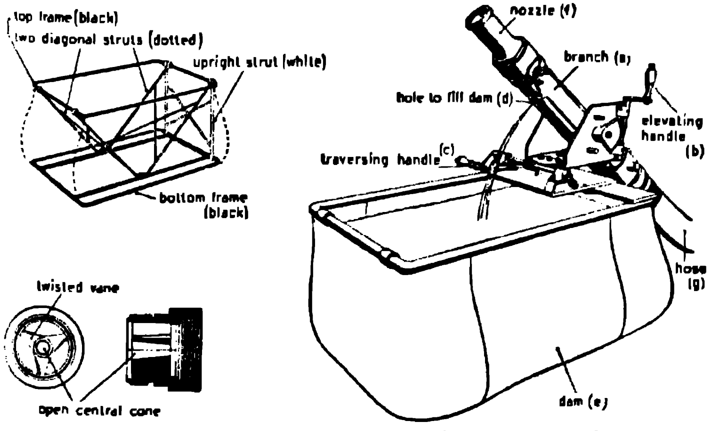


Fig. 32. Deluge set. Top, left : dam frame. Bottom, left : diffuser fitting. Right : general view.

required position it can be left unattended and enables fire streams to be used which would be too large to be man-handled.

A diffuser fitting (Fig. 32, *bottom left*) has also been issued for use with the deluge set and the radial branch set ; this should be used where a large quantity of diffused water is required. The method of attaching the diffuser fitting, which is in effect an extension piece of the branch, is to unscrew the ordinary nozzle on the deluge set, screw on the diffuser fitting to the branch and then to screw the ordinary nozzle on to the male screwed portion of the diffuser fitting.

The diffuser consists of a short brass casting having three internal vanes arranged with a slight spiral so as to impart a twist to the water as it issues from the nozzle. The stream then breaks up into a heavy mist which is used for drowning out a fire.

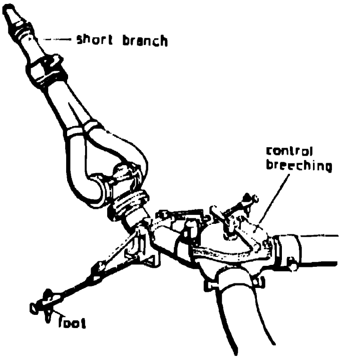


Fig. 33. Portable monitor.

(ii) *Other Portable Monitors.* Various types of portable proprietary monitors have been developed. In almost all cases these possess swivelling joints which permit of the jet being directed as required. Some are fitted with extensible feet to give a firmer grip on the ground. One such monitor is illustrated in Fig. 33. It will be noted that a standard short branch is employed and that the control collecting breeching allows one line of hose only to be employed, if the nozzle size permits of this.

(*b*) *Immovable Monitors*

(i) *Fireboat's Monitors.* These are almost invariably rigidly connected to the deck and sometimes have permanent piping arrangements from the pumps. Those of the largest size may have as many as eight inlets, each with its own hand-controlled valve and a main control valve for the monitor jet itself. These monitors are usually of the " straight through " type and with an unlimited supply of water can deliver up to 3,000 g.p.m. through a 3½-in. nozzle at a nozzle pressure of 100 lbs. per sq. in. Elevation and direction of the fire stream are almost invariably effected through gears, the monitor being mounted in many cases on the foc's'le. As these monitors form an important part of the equipment of a fireboat they are more fully dealt with in the chapter on that subject.

(ii) *Turntable Ladder Monitor.* Almost all turntable ladders are also equipped to act as water towers, and for this purpose carry at the head of the ladders a special monitor. This consists of a swivelling branch fitted with a hand lever by which the jet is directed. Whilst the branch may be elevated or depressed to throw a jet in the vertical plane of the ladder, lateral movement is limited to approximately 12 deg. to either side. In operation the jet should be kept in the same vertical plane as the ladder, since an oblique jet is liable to cause undue strain on the ladder. The construction and use of this monitor is fully dealt with in the Chapter on " Turntable Ladders."

5. BRANCH HOLDERS

As their name implies, branch holders are used to take either part or the whole of the weight and reaction of a charged branch. They require the attendance of at least one man to direct the stream, and hence must be distinguished from monitors and from portable directors or ground monitors, which can be left unattended except when being used at very low elevation.

Branch holders vary considerably in minor details throughout the ex-regular brigades. The simplest form (Fig. 34, *left*) consists of a solid metal bar about 5 ft. long with a sharp point at one end for obtaining a purchase on the ground: close to the other end is a wooden handle protruding either side at right angles to the bar to enable the fireman to direct the branch. The delivery end of the hose and the branch are laid along the bar and the branch is strapped in position with the nozzle protruding over the end of the holder. The operator must direct the jet, both for direction and elevation, the holder serving to take some of the weight and much of the reaction of the branch. The operator should stand straddling the hose, grasping one handle in either hand. The branch holder may be directed almost vertically or lowered to an angle of 35 deg. with the ground; any angle of depression less than this is dangerous as the pointed end may fail to bite into the ground. The branch holder is normally only employed where a jet must be in use for some considerable time.

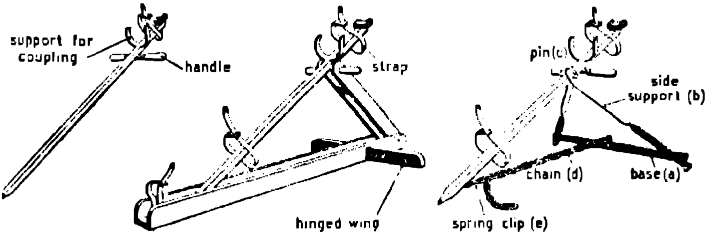


Fig. 34. Branch holder and portable directors. Left: emergency type branch holder. Centre: wooden frame portable director. Right: steel frame portable director.

6. PORTABLE DIRECTORS

Occupying a place midway between the branch holder, which requires the constant attendance of a branchman, and the monitor, which can normally be left to work entirely unattended, is the portable director or ground monitor, which consists essentially of a holder made either from wood or metal to take the standard emergency short branch.

The object of the ground monitor or portable director is to supply a portable and inexpensive device by means of which it is possible to save man-power when large fire streams have to be used, and to leave fire streams unattended when they have to be operated in exposed conditions where the heat or falling débris would make it undesirable to leave men in charge.

The wooden portable director (Fig. 34, *centre*) is of simple construction and can easily be made up locally. It consists of a wooden frame, about 6 ft. in length and 7 in. wide, which rests on the ground. To the front end of this frame is fixed by a swivel connection a wooden support 3 ft. long, to which an ordinary type emergency branch holder can be fitted. The handles of the holder are used to form a swivel at the head of the support. By raising or lowering the wooden support, and fixing the point of the holder in holes cut in the base of the frame, the holder is rigidly held at any angle of elevation. The branch and hose are attached to the holder in the usual way. The hose is secured to the rear end of the frame to keep it in line with the branch and stream of water. The device is suitable for use with nozzles up to 2-in. diameter. At all usual angles the branch is held securely under pressure without any manual aid, but if it is to be used at a low elevation, say under 25 deg., it may be found that there is a tendency for the unit to be forced backwards by the reaction of the fire stream. This tendency can be overcome by placing sandbags or other weights against the two hinged wings attached to the frame. These wings also serve to give greater lateral stability to the director as a whole.

A director of metal construction (Fig. 34, *right*) has also been designed. It is collapsible, and easy to carry. This device consists of an angle iron strut (*a*) with two hinged flat bar legs (*b*) forming a triangle to the apex of which a standard branch holder is secured by a pin (*c*) inserted in a hole drilled through the stem a few inches below the handles. A chain (*d*) is fixed to the centre of the triangle base and a spring clip (*e*) is fastened to any link to give the desired elevation.

This director can be used with nozzles up to 1½-in. diameter in conjunction with an ordinary branch and hose with 2½-in. couplings. Care must be taken, when operating on smooth hard surfaces at low elevations, that the point of the branch holder secures a hold and, if necessary, a suitable indentation can be made with a fireman's axe. The director is also suitable for use with larger nozzles up to 2-in. diameter, in which case a special branch must be employed to take 3½-in. hose and standard radial branch nozzles, but it is then advisable to have two men in attendance.

By allowing the branch and about 9 ins. of the hose to project beyond the end of the branch holder the fire stream can be deflected over a considerable area without moving the director itself.

COLLECTING HEADS AND FOOT VALVES

Certain fittings used by the Fire Service allow water to pass in one direction only. This is effected by means of non-return valves. The more important of these fittings are: (1) collecting heads (2) foot valves.

1. COLLECTING HEAD

This was often but incorrectly known as a collector box. It consists of a metal casting (Fig. 35), usually of aluminium, fitted with two, three, four, five or six inlets for delivery hose and a single female suction coupling for attaching to the suction inlet of a pump. Each hose inlet is fitted with a non-return valve.

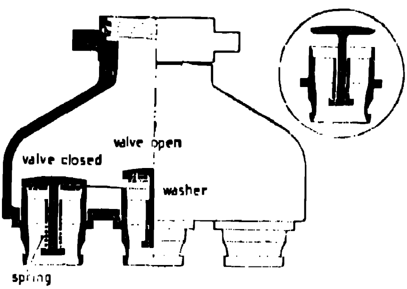


Fig. 35. Collecting head (three-way): (*inset*) alternative type of valve seat.

The non-return valve consists of a metal casting screwed into the body of the collecting head and fashioned at one end as a male instantaneous or a female thread hose coupling. The valve is mushroom-shaped with either a synthetic rubber or a metal to metal ground face and is held against a seating by means of a spiral spring.

The action of water entering the inlet under pressure forces the valve off its seating and the water then passes through the outlet. On the pressure being reduced the valve is brought back on to its seating and the passed water is unable to return. The valve lift must not be less than ⅝ in. Certain non-return valves (Fig. 35, *inset*) are made with a ground-in seating to a depth of ¼ in.

Collecting heads issued under the emergency scheme for light trailer pumps have two, and for large trailer pumps and heavy units three inlets in line, whilst extra heavy units are equipped with a circular collecting head with five inlets. The design of collecting heads for ex-regular appliances varies considerably but generally they are of the four-in-line type, though up to six inlets in a line may be encountered.

Collecting heads issued under the emergency scheme are tested to a pressure of 100 lbs. per sq. in. To obtain maximum efficiency on a relay the intake pressure should be maintained only slightly above atmospheric. Under no circumstances should full pump pressure be put on a head as a serious accident might occur.

2. FOOT VALVE

This consists of a metal suction strainer fitted with an extension tube in the casting between the strainer proper and the coupling. In this extension a flap-type reflux valve is fitted in such a manner that the water rising up into the suction forces it open. If the pump is shut down for any reason, immediately the flow ceases in the suction the flap valve falls back on to its seating thus keeping the suction fully charged. The pump should not, therefore, require re-priming when it is started up again. As it is necessary to empty the suction before withdrawing it to make up, a device is employed to trip the valve. To a ring fitted on the upper side of the valve is attached a wire passing out of the extension tube through a small hole and carried through an eyelet fitted to the outside of the casting up to the pump operator. To clear the suction the wire is pulled, thus opening the valve. Foot valves were used to some extent with reciprocating pumps but are now very rarely employed.

HARD SUCTION FITTINGS

1. SUCTION STRAINERS

To prevent large solid objects which might damage the pump from being drawn into the suction when working from open water, strainers attached to the lower end of the suction hose are employed. These strainers are of two types :

(*a*) Metal Strainers.
(*b*) Basket Strainers.

(*a*) *The Metal Strainer.* This consists of a metal fitting (Fig. 36, *right*) usually cylindrical but sometimes box-like in shape, perforated with holes to allow water to enter. It is fitted with a female suction coupling for connection to the suction hose. Strainers are made in a large number of sizes to fit the various diameters of suction. Whilst all strainers issued under the emergency scheme are cylindrical in shape, those supplied with ex-regular appliances varied considerably.

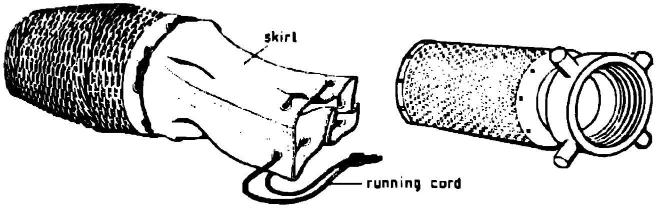


Fig. 36. Strainers. Left : basket type. Right : metal type.

Some are fitted with a foot valve (see above), whilst others are of the low-level type designed to rest on the bottom of the water supply and operate in a minimum depth (Fig. 37).

A typical strainer of this type consists of a shoe-shaped outer perforated cover (*a*) with a flat bottom to rest on the bed of the stream, etc., from which the supply is being drawn. Inside this casing a shield (*b*) is arranged so that water can only be drawn into the suction around the underside. Provided, therefore, that the underside of this shield is submerged the vacuum can be maintained, and water will continue to flow up the suction. The shield (*b*) and end plate (*c*) with coupling (*d*) for attaching to the suction hose can be removed for cleaning by undoing a series of nuts. In order to bring the strainer as low as possible the coupling has no lugs but a series of slots (*e*) into which a "C" spanner (*f*) can be inserted for tightening.

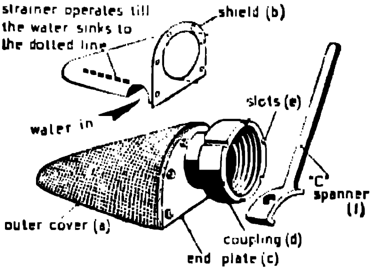


Fig. 37. Strainer : low-level type.

(*b*) *The Basket Strainer.* This (Fig. 36, *left*) is used in conjunction with the metal strainer but never alone. When resting on a soft surface such as mud, the copper strainer tends to sink in, covering a considerable percentage of its surface area which then ceases to be available as a strainer. The basket strainer, acting as an outer shell, rests in the mud, and having a larger surface area, still leaves a considerable proportion exposed, and allows the copper strainer to function unimpaired. The basket strainer also tends to protect the copper strainer from damage. It also assists in removing from the water entering the suction, particles which, though small enough to pass through the perforations in the metal strainer, would tend to damage the pump mechanism. It is cylindrical in shape, of woven wicker work with one open end to which is attached a piece of canvas known as the skirt. This has a running cord which allows it to be drawn tight around the suction thus preventing the water from entering the mouth of the strainer without passing between the basketwork.

2. SUCTION CRUTCHES

When a pump is set into a canvas dam with self-supporting walls the weight of the suction tends to depress the walls and allow the water to overflow. To take the weight, a suction crutch is generally employed. These crutches are, however, now generally used whenever it is necessary to support a length of suction and prevent it chafing when passing over low walls or the sharp edges of dams, etc.

The suction crutch (Fig. 38, *left*) consists of a length of metal approximately 2 ft. long and 4½ ins. wide which is supported by collapsible tubular steel legs. Metal frames bent to fit the curve of the suction are mounted on top of the crutch.

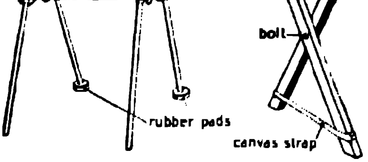


Fig. 38. Suction crutches. Left : steel type. Right : improvised wooden type.

A simple form of suction crutch (Fig. 38, *right*) can be constructed from two stout wooden poles approximately 5 ft. long. Each pole should be drilled about one foot from one end, and the two joined by means of a bolt passed through these holes. The poles should then be opened until they form a suitable aperture to receive the size of suction in use, and the bases linked by means of a length of rope or canvas strap to prevent them opening further. When not in use the crutch can be carried on the appliance folded flat.

STANDPIPES

Standpipes are often known as hydrant heads and shafts. They are used to bring the outlet of a hydrant above ground level. This is necessary as :—

1. in some cases the hydrant outlet is at a considerable depth and it would be difficult if not impossible to couple up the suction or delivery hose.
2. the hydrant pit is of very restricted dimensions and access to the outlet is difficult.
3. serious kinking of the hose is avoided ; this is of particular importance in the case of suction hose.
4. certain types of hydrants (the ball hydrant and the old fire plug) often have no command valve and the standpipe provides the necessary control. In these cases a special standpipe must be employed.

In most types the standpipe shaft and the standpipe head are separate fittings which can be disconnected, but which are normally kept permanently connected. Unless specifically referred to otherwise, the term standpipe will be used to denote the complete fitting and will include the head.

The standpipe shaft consists of a length of brass, or more commonly, copper piping, the length of which may vary considerably according to local preference, but the diameter of which is usually 2½ to 2¾ ins. The standpipe shaft connects at its lower end with the hydrant outlet by any one of a number of means, whilst at its upper end, where a separate head is fitted, the appropriate standard hose coupling is employed.

I. OUTLETS

The principal differences between standpipes arise in the method of connection to the hydrant. Since hydrants have been installed over a period of more than 100 years by many hundreds of different authorities very considerable variations in outlet are to be found. There are in this country some 53 types of hydrant outlet, none of the standpipes for which are interchangeable.

Of these many types, however, only some five or six are in general use. These are the round thread, the " V " thread, the instantaneous, the bayonet lug, the ball hydrant, and very occasionally the fire plug.

Since the standpipe for one type of outlet cannot be used on another, appliances must be furnished with standpipes having at their lower ends connections appropriate to the hydrant outlets in their area. This has, in the past, led to difficulties, for an appliance moving into another area where the hydrant outlets are different may find itself unable to get to work from a standpipe, and may be forced to get to work from the hydrant pit. The various methods of doing this are set out in the Chapter on "Practical Pump Operation." These methods cannot be employed in the case of ball hydrants, since the use of the appropriate standpipe is necessary to open up the hydrant. In order to facilitate operations, therefore, stocks of spare standpipes appropriate to the local hydrants are maintained at focal points such as reinforcement bases and issued to those incoming appliances which would not otherwise be able to get to work.

(a) Round Thread and "V" Thread. The round thread (Fig. 39, i) and "V" thread (Fig. 39, ii) hydrant outlets are male, of the standard hose coupling size to take standpipes with female bases, or hose may be connected directly or by means of adaptors where necessary.

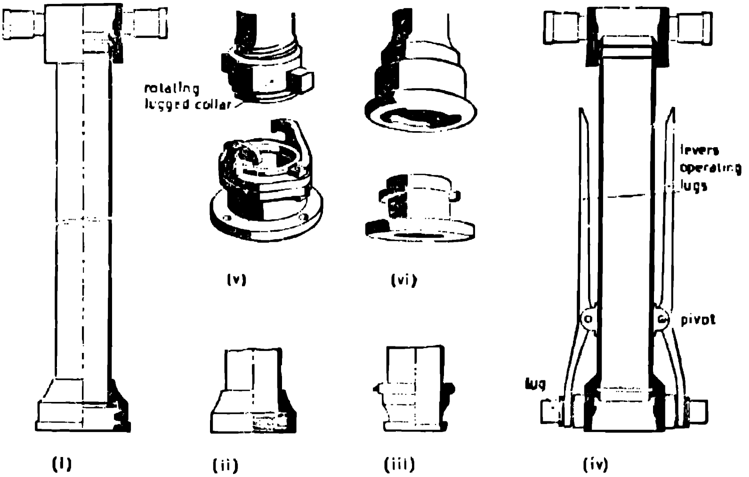


Fig. 39. Some typical standpipe bases: (i) round thread; (ii) "V" thread; (iii) male instantaneous; (iv) female instantaneous; (v) lugged; (vi) bayonet.

(b) Instantaneous. Instantaneous hydrant outlets may be either female (Fig. 39, iii) or male (Fig. 39, iv). The standpipe to attach to a male instantaneous coupling on the hydrant is fitted at its lower end with a female instantaneous coupling. In order to operate this in the confined space of the hydrant pit it has two levers passing up either side of the standpipe, attached at one end to the female lugs of the coupling and pivoting on a fulcrum some 8 ins. above. By pressing these levers towards the pipe the female lugs are withdrawn, allowing the standpipe to be removed. To connect the standpipe it is of course firmly pressed down on the outlet. The advantage of the lever standpipe is that there is

practically no limit to the depth below ground at which it may be made to operate, *i.e.*, as in arctic or semi-arctic conditions where water mains have to be exceptionally deep to prevent freezing.

(*c*) *Ball.* In the case of the ball hydrant (Fig. 40) the connection is normally of the lug type, but as the hydrant does not possess a separate command valve it requires a special attachment in the standpipe to open it. A steel rod (*a*) passes through a packing gland (*b*) in the standpipe head and continues straight down the inside of the standpipe through a threaded collar (*c*). To the lower end of this rod is attached a cup (*d*) to bear against the exposed top of the ball (*e*) in the hydrant outlet. By means of a handle (*f*) at the top of the rod the latter is turned so that the threaded collar in the standpipe forces the rod downwards; the cup attachment is pressed down on the ball forcing it down into the body of the hydrant and thus allowing the water to enter the standpipe.

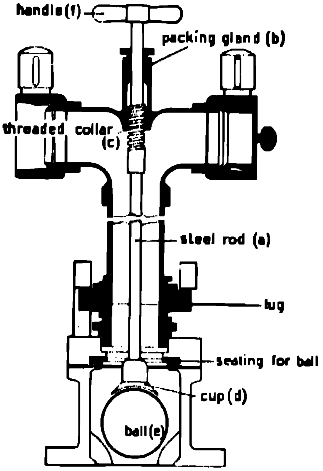


Fig. 40. Standpipe : ball type, with lug connection.

(*d*) *Bayonet and Lug.* The bayonet or lug connection may be fitted to a screw-down type of hydrant in addition to a ball-valve hydrant. The special type of standpipe necessary in the latter case may also be used on the former. The lug connection (Fig. 39, v) consists of a female coupling on the hydrant in the form of two right-angled lugs, diametrically opposite each other, one on either side of the orifice, which is slightly enlarged to take in the male coupling on the standpipe. The male coupling has two large square-shaped lugs which engage the right-angled lugs of the female. In the bayonet type (Fig. 39, vi) the base of the standpipe is slotted to engage small wedge-shaped lugs in the hydrant outlet.

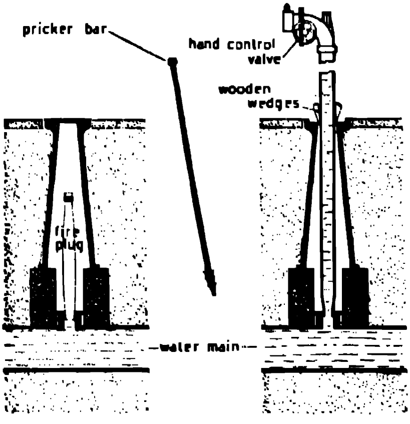


Fig. 41. Standpipe : fire plug type.

Most of the standpipes fitted with a bayonet or lug connection have a pair of short handles at the top for assisting in making the connection to the hydrant.

(e) *Fire Plug*. The standpipe for a fire-plug outlet (Fig. 41) possesses a sharp tapering end instead of a hydrant connection. On the removal of the fire plug by means of a pricker bar, the standpipe is driven into the plug outlet by hand and is then hammered in by means of a lead mallet to make a tight fit. The top of the pipe has a right-angled turn and is surmounted by a flat boss to give a surface on which to strike the mallet. At the end of this right-angled bend a hand control valve is fitted and by means of flanged face plates an instantaneous female hose coupling is attached in place of the more usual standpipe head.

2. SHAFTS AND HEADS

Standpipe shafts vary considerably in length owing to differences in the depth of hydrant pits, and appliances working outside their own areas may find that the standpipes carried are not long enough, even though the hydrant outlets may be the same.

A fitting known as a hydrant extension piece is carried on appliances in some localities to overcome this difficulty. This consists simply of a small standpipe shaft, about 12 ins. long, which is inserted between the hydrant outlet and the standpipe proper.

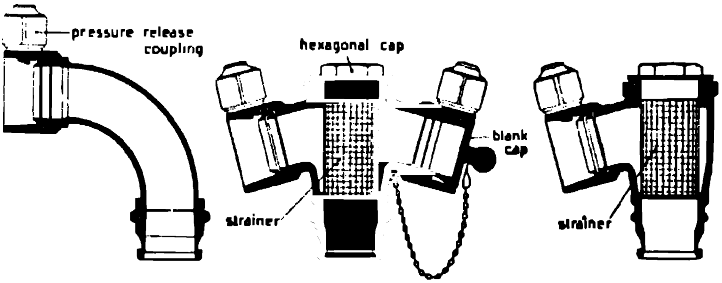


Fig. 42. Standpipe heads, emergency types. Left: open type. Centre: filter type, two outlets. Right: filter type, one outlet.

Standpipe heads (Fig. 42) vary greatly and may have either single (*left and right*), or double (*centre*) outlets with the appropriate hose couplings. In one emergency type (*centre and right*) a strainer is fitted in the head, access to the strainer being obtained by unscrewing a hexagonal cap. The connection between the head and shaft may be fixed, or may permit the head to swivel. In the latter case a swivel gland is incorporated, or, in the case of the standpipes issued under the emergency scheme, a swivel action is obtained, since the joint is made by a male instantaneous connection on the head and a female instantaneous connection on the shaft.

These heads are fitted locally with shafts having at their lower end the coupling suited to the local hydrant outlet. Heads carried on ex-regular appliances may vary greatly, some (apart from those used

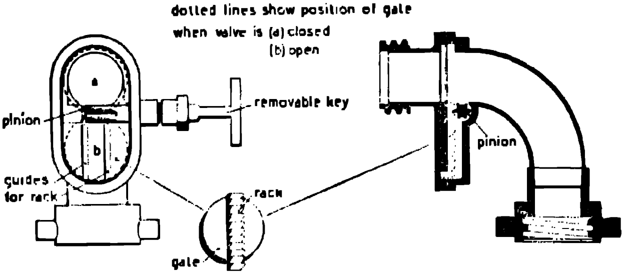


Fig. 43. Standpipe head : rack and pinion valve.

on fire plugs) are fitted with valves to control the flow of water. These valves are often of the rack-and-pinion type (Fig. 43).

CLEANING HOSE FITTINGS

As far as personnel permits, all equipment should be regularly cleaned. Apart from the question of smartness, the advantages of carrying this out systematically are that when fittings are cleaned they can at the same time be inspected for condition, that the crew of the appliance are familiarised with the gear carried on the appliance and that every man knows immediately where each item can be found when working in the dark.

Discretion must be employed, however ; brass polish should not be used on chromium-plated articles, and all residue from the polish or paint must be carefully removed, the more especially when it might block holes or passages in the equipment or cause it to stick in working. Nozzles depend for their efficiency on the true circular shape of the orifice and on an undamaged lip. On no account should the inside of nozzles be cleaned by pulling a rag backwards and forwards through the nozzle. This not only in course of time wears the bore to an irregular shape but destroys the knife-edge of the lip which is essential to maximum efficiency.

HOSE RAMPS

One of the major problems in dealing with large fires in urban areas is the obstruction caused to traffic by the numerous lines of hose which almost invariably must be laid across roads to make use of all available sources of water. Whilst wheeled vehicles can force their way over a line of charged hose, particularly of the smaller sizes, this causes severe strain on the hose and may lead to serious chafing, or, if the vehicle is heavy and presses the hose flat, may momentarily cut off the flow and set up shock waves which burst the hose. To enable vehicles to cross lines of hose, special fittings known as hose ramps are employed. These are designed to provide a sloping path up and over the hose, and a well-designed ramp should prevent contact of the tyre or wheel of the vehicle with the hose. Ramps are almost invariably designed to accommodate 3½-in. diameter hose and can therefore be used with all types of delivery hose.

I. WOODEN RAMPS

The ramps issued in large numbers to the National Fire Service consist of a series of wedge-shaped pieces of wood (Fig. 44) joined together by either straps or ropes so as to provide a channel between them of about 3½-in. width, in which a length of hose can be laid, the wedges making an incline on each side to carry the wheels of passing vehicles over the hose. It has been found that the performance of these ramps can be greatly improved by attaching an apron of old belting (Fig. 44, ii) or even stout discarded hose opened out. This reduces the tendency of vehicles endeavouring to mount the ramps at excessive speed to push them along in front of the wheels. The weight of the vehicle is first transferred to the apron and thus holds the ramp firmly in position as the wheel meets the incline.

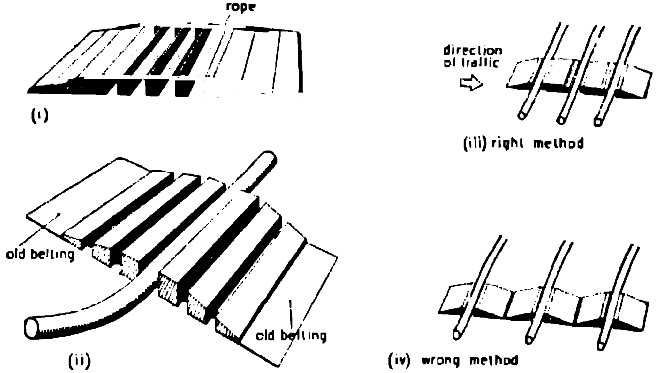


Fig. 44. Hose ramps : (i) multi-channel ramp ; (ii) standard emergency type ; (iii) right method of ramping more than one line of hose ; (iv) wrong method of ramping more than one line of hose.

When more than one line of hose must be ramped and only single-line types are available, the ramps should be arranged as shown in Fig. 44, iii. This obviates the series of troughs formed if ramps are laid one after another (Fig. 44, iv) and greatly reduces their displacement due to traffic movement.

Ramps are also issued with a rectangular section which is connected between the two wedges to provide two or more channels in which two or more lines of hose can be laid (Fig. 44, i). A modification of this type of ramp can be expanded to take additional lines of hose by means of extra sections linked by interlocking metal rods (Fig. 45, i).

2. STEEL RAMPS

An additional type of ramp is designed for use where heavy and continuous traffic must be provided for. This consists of rigid

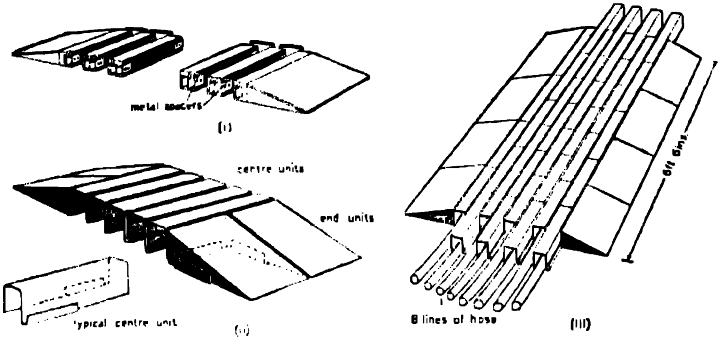


Fig. 45. Hose ramps : (i) emergency multi-channel type linked by metal rods ; (ii) steel channel section ramps ; (iii) staggered arrangement of steel channel section ramps.

metal sections built up from rolled steel. The angle of the slope of the approach varies between 8 and 12 degs. (Fig. 45, ii).

These ramps can be arranged to accommodate any number of lines of hose by the addition of extra channels. The individual sections are interlocking, but where three or more central channels are employed firmer bonding is obtained by staggering alternate central channels by half a length. This breaks the joints and does not permit movement along a whole section (Fig. 45, iii).

With ramps which are only between 2 and 3 ft. in length it is of course necessary to lay down, for each length of hose, two ramps at a sufficient distance apart to take the nearside and offside wheels of vehicles. Where there is great variation in the width of vehicles, a pair of ramps for each wheel track may be necessary. Some appliances, however, carry longer ramps which may range up to 8 ft. in length, only one of which is necessary per length of hose.

3. IMPROVISED RAMPS

An improvised hose ramp which will serve to reduce the damage to hose can be made from old lengths of discarded hose. Some 3 to 4 ft. is cut off and one end turned over and riveted. This end is then tightly packed with a wad of waste and the length of hose filled with sand tightly rammed. The other end is treated in like manner. The filled lengths are then linked by two straps, also made of discarded hose, so that the charged hose can lie between them (Fig. 46, *left*). In place of the sand-filled lengths of hose cut down

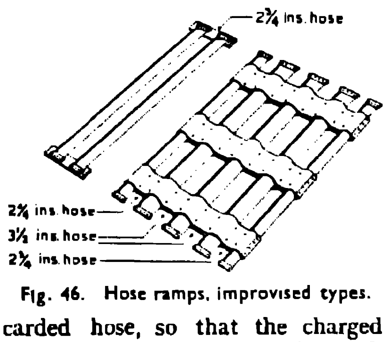


Fig. 46. Hose ramps, improvised types.

timber, such as old pit props, etc., has also been successfully employed.

A larger ramp of the same type (Fig. 46, *right*) can be constructed of sand-filled lengths of 2¾-in. and 3½-in. discarded hose, the larger diameter lengths being placed in the centre. This pattern will take both sizes of delivery hose.

Owing to the war-time shortage of rubber, rubber-lined hose should not be used in the construction of ramps.

4. TRAMWAY RAMPS

Since tramcars which run in tracks cannot use the normal type hose ramp a special type of ramp (Fig. 47) for trams using overhead current has been in use by the Glasgow Corporation Transport Department for some years.

The ramps are approximately 30 ft. in length, and are divided into five sections. The central section forms a bridge-piece approximately 6 ft. long by 4½ in. high, in which are cut six rectangular openings, each of sufficient size to accommodate two lines of hose. Twelve lines in all can thus be protected by one ramp. The side sections, which are joined to the centre section by heavy bolts, are inclined in order to return the tram wheels to the track with the minimum of dislocation. The ramps are held in position by metal guides which register in the grooves of the track. The weight of these ramps (approximately 8½ cwt.) makes them unsuitable for carrying on Fire Service appliances. They are stored at various tramway depots and when required are delivered and erected on the scene of the fire by the maintenance staff of the tramway department.

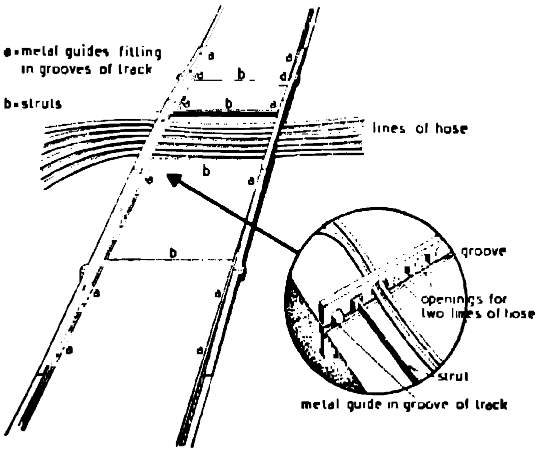

a = metal guides fitting in grooves of track
b = struts
a
b
lines of hose
groove
openings for two lines of hose
strut
metal guide in groove of track

Fig. 47. Tramway hose ramp as used in Glasgow.

PART I CHAPTER 6

LADDERS

THIS chapter will be confined to a description of those ladders which are carried into position and extended by hand. Special forms of ladders, such as those used in turntable ladders and escapes, are dealt with in separate chapters.

The ladders described here are employed chiefly for rescue purposes where wheeled escapes cannot be used, and to obtain access to the upper floors and roofs of buildings; but their other uses are innumerable; as, for example, for climbing about on roofs after access thereto has been gained; mounting chimney stacks; scaling walls; bridging between buildings or across unsafe floors; replacing indoor stairways; as stretchers, and for descending into basements or ships' holds.

Ladders are an important part of the equipment of the fireman, and it is essential that both their construction and use should be understood.

The correct names of the parts of a ladder are shown in Fig. 1.

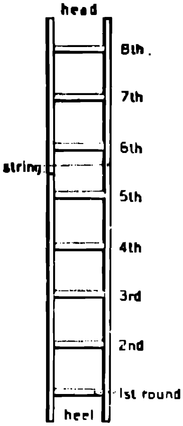


Fig. 1. The principal parts of a ladder.

TYPES OF LADDER IN USE

A number of different types of ladder carried and extended by hand have been developed for Fire Service work. The most widely used are :—

1. First-floor ladders (non-extension type).
2. Extension ladders.
3. Hook ladders.
4. Scaling ladders.

1. FIRST-FLOOR LADDERS (NON-EXTENSION TYPE)

The first-floor ladder was used mainly by the larger city and town brigades and is carried on those ex-regular appliances which have a 50-ft. or 55-ft. wheeled escape. Some of the emergency escape carriers have also been provided with a similar ladder.

Construction. The ladder is 15 ft. 8 ins. long and weighs about 45 lbs. The rounds are secured to the strings by gun-metal sockets so that they cannot turn. A wrought-iron hook is bolted to the underside of each string at the first round to fit on to one of the rounds of the escape, so that the ladder can be used as an additional extension.

The standard type of ladder, as fitted to the 50-ft. escape, is too wide to attach to the upper extension of the 55-ft. escape, and a narrower pattern is, therefore, provided for the 55-ft. escape.

Standard Test. First-floor ladders in use in the National Fire Service at the time of publication of the *Manual* are tested monthly, after use at a fire, and whenever used for drill. The ladder is first carefully examined. The head of the ladder is then secured and the rounds jumped as far as possible, with the feet well apart. The ladder is then reversed and the remaining rounds jumped. The hooks are examined for rigidity.

Use. The first-floor ladder, as its name implies, is primarily used for entering the first floor of a building. It can also be employed as an extra extension to an escape, and for this reason is sometimes known as an " emergency " ladder. This is done by raising the ladder above the head of the escape, slipping the hooks on a convenient round, and lashing with the escape line. The series of knots used for this purpose will be found described in the Chapter on "Escapes." The additional height thus achieved must not exceed 10 ft., the lower part of the ladder being used as an overlap for lashing. To ensure that sufficient overlap is allowed, the round on the escape engaged by the first-floor ladder should be painted white to serve as a guide. The first-floor ladder is also useful, when attached in this manner, for negotiating parapets or other projections on the face of a building.

2. EXTENSION LADDERS

Extension ladders are used at fires in circumstances where a wheeled escape is not necessary or cannot be employed owing to restrictions of space, *e.g.*, in narrow passages, gardens, etc. They are also frequently used as internal or external means of access where a stairway has been damaged by fire. Two ladders may be used together to form a step ladder (see later).

In addition to the trussed type of extension ladder used by Fire Brigades prior to nationalisation, there are three types of emergency extension ladder in use in the National Fire Service. The largest when fully extended is 40 ft. long, the medium size is 30 ft., and the small size is 13 ft.

(a) Trussed Extension Ladder. Many ex-regular appliances throughout the country carry the trussed-string type of extension ladder. This type is strong and simple in operation. Each section is approximately 24 ft. long, the width of the main section being 18½ ins. outside and that of the upper section 15 ins. The total weight of the ladder is about 160 lbs., and it is fitted with an extending line consisting of 1¾-in. manila which passes between the sections over a head pulley on the main section. The ends are attached to a lever in the middle of the pawl shaft on which two pawls of the claw pendulum type are mounted, which operate so that the ladder, when extended, does not depend upon the strength of the rope. Plenty of slack is provided on this line to allow for shrinkage when wet. It should never be shortened nor tied in a knot when the ladder is stowed. The loose portion should be folded around the bottom rounds of the ladder in such a way that immediately the ladder is erected and the rope pulled the slack releases itself automatically. The two sections can be readily separated and used

individually. When the ladder is pitched the trussed side must face the building.

(*b*) *40-ft. Extension Ladder.* This type of ladder, sometimes known as an " Edinburgh " ladder, was issued to some Fire Forces in lieu of wheeled escapes, but owing to certain disadvantages in manipulation its issue has been discontinued. It is of very robust construction and has a solid heel board lying horizontally and attached to the strings with metal braces. This board extends 1 ft. on each side of the ladder and is rubber shod for the full length of the underside. The width of the main ladder is 22 ins., and the rounds are strengthened by wrought-iron tie rods under the 2nd, 4th, 7th, 10th, 13th, 16th and 18th rounds.

(*c*) *30-ft. Extension Ladder.* This is the most widely used type of ladder in the Fire Service.

Construction. The 30-ft. emergency extension ladder (Fig. 2) consists of a main ladder with a top or sliding extension, each section being 15 ft. 9 ins. long. The total weight of the ladder is 112 lbs. The external width of the main ladder is 15¾ ins., and the distance between each round is 9½ ins. The overall length of the ladder when closed is 15 ft. 9 ins. (but certain ladders are 16 ft. 3 ins.), and when fully extended 28 ft. 4 ins. The extending line (*a*), made from 1¾-in. manila, is rove through a pulley (*b*) secured to the underside of the top round of the lower extension. It is then led down the front of the ladder and secured by an eye splice to a lever (*c*) mounted on a rotating shaft above the bottom round of the upper extension. The other end of the line is led behind the main ladder, underneath the bottom round and spliced in, thus providing an endless line by means of which the ladder can be extended and the pawls (*d*), which are mounted on the rotating shaft, engaged and tripped. Guide plates (*e*) are fixed to the bottom of the top section and these fit into grooves (*f*) which are cut into the

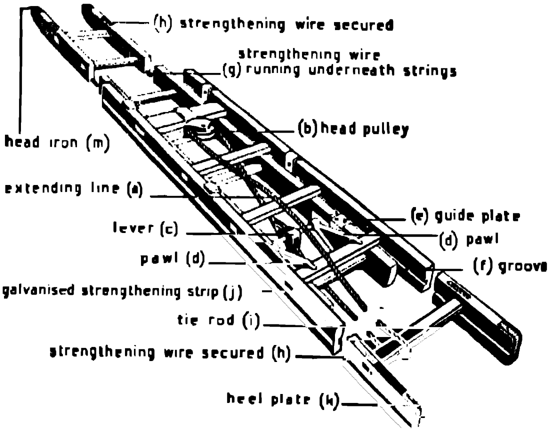

(h) strengthening wire secured
strengthening wire (g) running underneath strings
(b) head pulley
head iron (m)
extending line (a)
lever (c)
pawl (d)
galvanised strengthening strip (j)
tie rod (i)
strengthening wire secured (h)
heel plate (k)
(e) guide plate
(d) pawl
(f) groove

Fig. 2. Head, heel and pawl mechanism of 30-ft. extension ladder, showing correct naming of parts.

inside of the strings of the main ladder, thus guiding the top section when extending. No safety stops are provided, and care should be taken that the top section is not extended above the white safety line painted on the side of the strings.

The ladder is strengthened by 5-gauge, 7-ply galvanised wire (*g*) which is stretched tautly along the edges of the strings of the main and top sections. The wire is secured by staples and screws at the head and heel of the ladder (*h*) and the rounds are strengthened by wrought-iron tie rods (*i*) under the 1st, 5th, 9th, 13th, and 16th rounds of the main and top sections. A galvanised strengthening strip (*j*) runs along the outside of each string of the main ladder. The heels of the strings of the main ladder are protected against wear by steel heel plates (*k*), which are corrugated to reduce the tendency of the ladder to slip when pitched on a hard surface, and the heads by head-irons (*m*). The ladder is finished with clear varnish, as a solid cover such as paint would hide incipient defects. Each ladder is inspected after construction, and is stamped on the face of the strings with the year of supply.

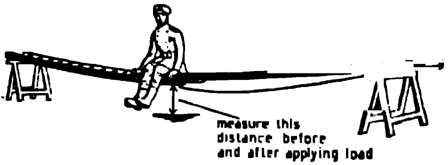

measure this distance before and after applying load

Fig. 3. Method of testing extension ladder

Standard Test. At the time of publication of the *Manual* the ladders are tested monthly, after use at a fire and more frequently still if used for drill purposes. The following procedure should be carried out when testing.

Each ladder is to be fully extended and placed horizontally across two trestles (Fig. 3) which should be positioned about 2 ft. from either end. The distance of a point in the middle of the span from the ground is to be measured, and the weight of one man of about 12 stone applied centrally. The ladder should return to the normal position when the weight is released (though a discrepancy of about half an inch may be found as a result of warping). After this test each round is to be jumped (Fig. 4).

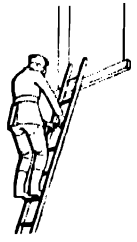


Fig. 4. Correct stance for jumping the rounds of a ladder. Note firm grip with both hands and feet well apart.

The extending line is tested by applying the equivalent strain of the weight of two men. When testing the extending rope the ladder is first pitched without extending against a building or wall, the weight of two men is then applied to the rope at the lowest practicable point as for extending the ladder, whilst two other men apply their weight to the extension to prevent it moving. The ladder is then drawn away from the building, extended fully and pitched again. The weight of two men is then applied at the lowest practicable point to the part of the line which lies at the rear of the ladder. The pulley wheel and pawls are to be examined and lubricated from time to time as required.

(*d*) ***Short Extension Ladder.*** This ladder, owing to its convenient size, is also very widely employed.

Construction. The standard short extension ladder (Fig. 5) consists of a main ladder and top or sliding extension, each section measuring 7 ft. 6 ins. long. The total weight is 30 lbs. The ladder is extended by raising the top extension by hand and allowing the retaining hooks fitted underneath the strings to drop back on to the required round of the main section. Great care must be exercised that the safety margin is not exceeded. Since no safety stops are fitted, white safety lines are painted on the strings as a guide to the limit of extension.

The width of the main and top sections is 14½ ins. and 11½ ins. respectively, whilst the distance between the rounds is 9½ ins. The overall length of the ladder when closed is 7 ft. 8 ins., and when fully extended 13 ft. 2 ins. Wrought-iron tie rods are fitted below the 1st, 5th and 8th rounds of each section. The ladder is strengthened by galvanised wire which is stretched taut on the edge of the strings, on the underside, and held in place by staples at intervals of 9 ins.

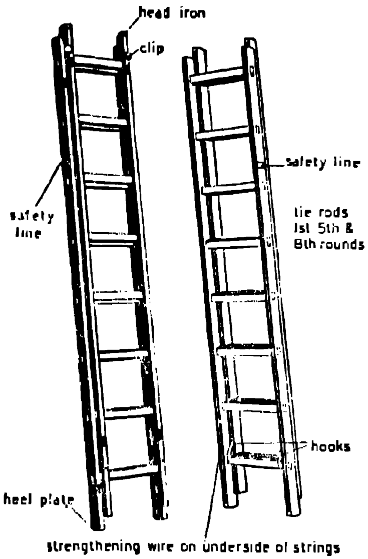

head iron
clip
safety line
safety line
tie rods 1st 5th & 8th rounds
hooks
heel plate
strengthening wire on underside of strings

Fig. 5. Short extension ladder, showing construction.

Standard Test. The following test is in force at the time of publication of the *Manual.* Short extension ladders should be tested monthly, after use at a fire, and when used for drill purposes. The ladder should first be carefully examined and the rounds jumped as far as possible with the feet apart. The ladder should then be reversed and the remaining rounds jumped. The metal parts should be closely inspected for rigidity, and fixing screws closely examined. The horizontal test described above for the 30-ft. extension ladder should not be used with the short extension ladder.

Use. The short extension ladder is a utility ladder which may be used for negotiating walls and for external first floor work. It is also sufficiently small for use inside a building, *e.g.*, to replace a damaged staircase, or to gain access to roof fires from the inside of the premises. The two sections of the ladder can easily be separated by sliding the top extension through the clips of the main ladder. The two sections can then be used as two 7 ft. 6 ins. single ladders which can easily be carried up an escape or extension ladder, and can also be used to form an improvised step-ladder (Fig. 22); or to scale a wall, one section being used for ascent and one for descent.

3. HOOK LADDERS

There are several types of hook ladders in use in the Fire Service. These include the London, Manchester, folding, American and the double-fixed hook patterns. There are also a few straight one-piece ladders made of duralumin or similar material, giving lightness combined with strength. The type most widely used in the National Fire Service is the London pattern described below.

Construction. The standard length of a London type hook ladder (Fig. 6) is 13 ft. 4 ins. The width is 10¾ ins. and the weight between 24 and 28 lbs. It is fitted with a hook (*a*) by means of which the ladder can be hooked on to window frames, parapets, etc., for the purpose of scaling buildings. It is also fitted with a steel ring (*b*) at the head of the ladder for receiving the hook of the hook belt (see below) worn by the man using the ladder.

The ladder is strengthened by steel pianoforte wire (*c*) stretched tightly along the inside of each string. It is further strengthened by three wrought-iron rods (*d*) ¼-in. diameter passing through both strings under the 2nd, 5th and 8th rounds and riveted on the outside with a copper washer. The three top rounds are specially strengthened by means of mild steel tubes passing through each round and both strings and also the shroud (*e*) (which contains the hook when folded) in order to take the strain of the hook when the ladder is in use. The whole of the construction of the ladder is such as to withstand suspended but not supported weight.

Steel toe pieces (*f*) which are fitted on the underside of the strings opposite the second round prevent the ladder from lying flush with the building, thus enabling a man's boots to obtain sufficient purchase on the rounds. Mild steel heel plates (*g*) are fitted to the heels of the strings to protect them against damage if the ladder is lowered too heavily to the ground.

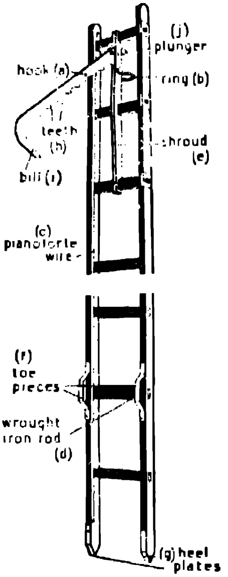


Fig. 6. Head and heel of hook ladder, showing correct naming of parts.

The hook is made of high tensile steel approximately 2 ft. 2 ins. long. On the underside are cut a number of teeth (*h*), usually eight, in such a fashion as to cause them to dig into any surface on which they rest and thus prevent the ladder slipping owing to the outward pull of the person climbing it. At the further end of the hook is a bill (*i*) 6 ins. long from crown to point. The hook is kept in position by a small spring-loaded plunger (*j*) which travels over an incline on the shoulder of the hook and drops into a hole, thereby keeping the hook rigid. The hook is painted white to facilitate working in the dark, but the underside, like the ring already mentioned, is kept highly polished to enable any defect or flaw to be discovered immediately.

Hook Belt. The hook belt (Fig. 7), which should be worn when the ladder is in use at fires or at drill, is made of saddle-girth webbing about 4½ ins. wide and 3 ft. 4 ins. long. It is lined with leather and fastened by straps (*a*) which buckle from left to right to obviate the risk of the loose end of the strap becoming caught in the trigger of the hook. This large spring hook (*b*) is rigidly fixed to the belt and is worn either on the left or right of the body, depending upon whether the climb is being made left-handed or right-handed. It is fastened by the wearer to the steel ring fitted to the head of the ladder. The belt is also fitted with a strap (*c*) to which an axe pouch may be buckled and a leather pouch (*d*) to contain a bobbin line (*e*). When the belt is put on, the straps should only be loosely fastened so that the belt can be readily pulled round to bring the hook into the correct position on either side of the body.

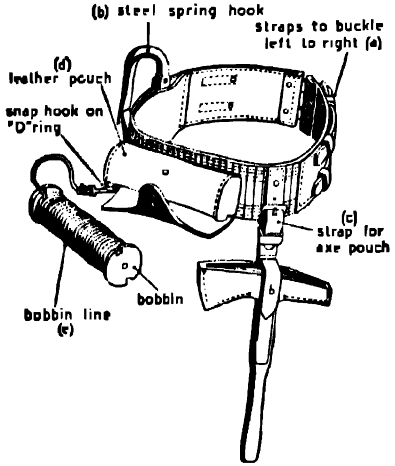


Fig. 7. Hook belt with close-type hook.

In an alternative form of hook belt (Fig. 8) the general construction of the belt is similar with the exception of the hook which is of a loose link type. This type of hook allows the wearer greater latitude of movement, but as it also permits the body of the wearer to come further away from the ladder it somewhat reduces the feeling of stability.

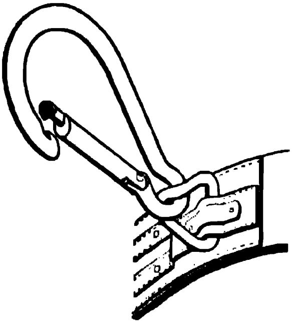


Fig. 8. Loose link type hook.

Acceptance Test. Before the ladder is accepted it is tested as follows: It must carry two men, weighing together 23 stone, with only the extreme point of the hook resting on a wall; and when supported with the hook downwards by two trestles 12 ft. 6 ins. apart it must bear a weight of 11½ stone applied to the centre.

Standard Test. (*a*) The ladder is placed against a wall or suitable structure with hook down towards the wall, as close in as the hook will allow. The ladder is lashed or held steady, and each round is then jumped in succession as far as possible, with the feet apart. The ends are changed and the remaining rounds jumped.

(*b*) The ladder is hooked on a wall or sill (Fig. 9) with a piece of wood 3½ ins. square under the extreme point of the hook and the ladder drawn out as far as the hook will allow. In this position the ladder should carry the weight of two men applied gradually.

(*c*) The ring must be kept highly polished and must be examined for incipient flaws.

(*d*) Hook belts are to be examined at the same time for any signs of perishing. Any belt showing undue signs of wear is to be sent in for repair.

Use. (i) *General.* This ladder is used to scale a building in order to effect an entry on any floor for the purpose of rescue or for searching the building. It may be used in this way from the head of an escape or extension ladder or in circumstances where it is not possible to employ other types of ladders to reach a particular floor of a building on account of the restriction of working space or height. The weight of more than one man should not be placed on the ladder except in an emergency, or when carrying out acceptance or standard tests.

A hook ladder depends for its stability and safety in use on the fact that the weight is applied to it *below* its point of suspension. When using a hook ladder, therefore this point should always be remembered, and the ladder should *under no circumstances* be used where this requirement is not fulfilled. As the point of suspension is the hook it follows that the whole of the weight must be taken by it, thus providing the necessary stability and ensuring that the teeth on the underside of the hook are forced into the material on which it is resting and prevent it from slipping.

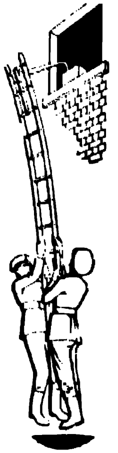


Fig. 9. Correct method of testing a hook ladder.

The greatest care must therefore be taken to verify that the toe pieces are not resting on any projection and taking part of the weight of the ladder. Further precautions which must be always observed are: that two ladders never override; that the hook is properly engaged (by inspection during the day and by feeling at night), and that the weight has been applied to the ring before letting go with both hands. Any weight must be applied below the point of suspension and evenly on either side, otherwise the ladder may become disengaged. The appropriate drills, and hints on

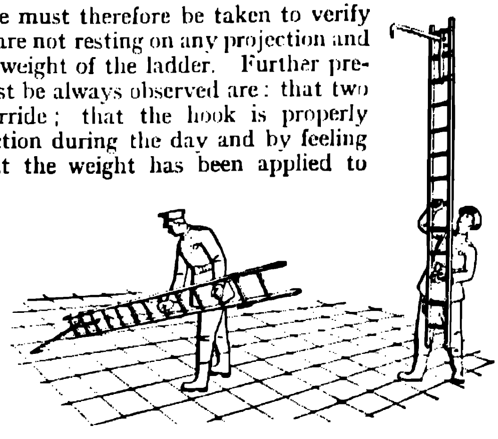


Fig. 10. Left : correct method of picking up a hook ladder. Right : correct method of placing a hook ladder into window.

the use of hook ladders are given in the National Fire Service Drill Book.

(ii) *Raising a Hook Ladder.* When raising the hook ladder from the ground (Fig. 10, *left*) the ladder should be grasped by the third and sixth rounds with the hook on the ground pointing away from the body. With the right hand on top and the left hand below, the heel of the ladder should be raised slightly and with a sharp cant, the head raised, and the ladder brought to a perpendicular position, keeping the ladder balanced with the hook facing away from the body. (Fig. 10, *right*).

To keep the ladder well placed and perpendicular when raising it to the floor above, the weight should be taken equally in both hands, and a smooth and rapid hand action on the strings should be used as the ladder is being raised, the hook being held away from the operator. When the bill of the hook has reached the required sill it should be turned inwards (Fig. 11) and the hook thrown in as far as possible. The ladder should be placed to the side of the window sill to allow as much room as possible for movement. (Plate 5.)

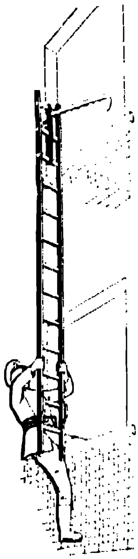
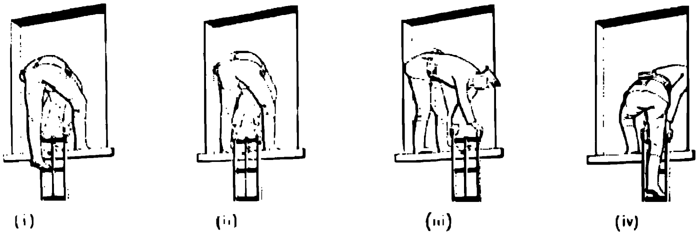


Fig. 11. Correct method of throwing a ladder to the second or subsequent floors. Note the rigid right leg, and position at one side of sill.

(iii) *To Enter a Building from a Hook Ladder or to Step on to a Ladder from a Building.* When a building is to be entered from a hook ladder the ladder should be mounted as far as the second round from the top and the top of the strings grasped with the index fingers down the outside. The right foot should then be placed on the sill (Fig. 12, i) followed by the left (Fig. 12, ii). A thrust upwards by the hands will then enable the man to stand upright.

To descend, the man should stand with the ladder on his left (Fig. 12, iii) and place his hands on the top of the strings, index fingers pointing downwards, keeping his back straight. The right foot should then be placed on the lowest of the rounds bearing the shroud (Fig. 12, iv), and keeping the weight on the



(i) (ii) (iii) (iv)

Fig. 12. Correct method of using a hook ladder. (i) and (ii) Entering a building. (iii) and (iv) Leaving a building.

head of the ladder he should swing out, placing his left foot on the round below and straightening his arms.

(iv) *To Move from a Hook Ladder to a Sitting Position on the Sill and from the Sill to the Ladder.* From the round below the shroud the left foot should be placed into the window with the leg straight and the hands holding the tops of the strings (Fig. 13, *left*) till the weight can be transferred to the leg and thigh resting on the sill. The right leg should then be held rigidly against the side of the building (Fig. 13, *centre*). If the ladder has been placed against the left-hand side of the sill the right foot should be placed into the window.

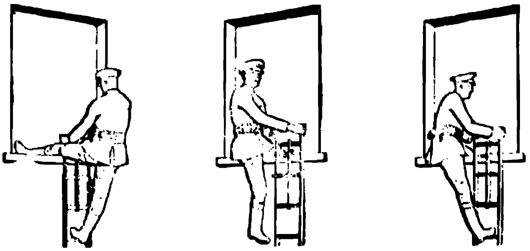


Fig. 13. Correct method of moving from a hook ladder to sitting position on a window sill and from the sill to the ladder.

To descend from the left-hand side of the ladder the hands should grasp the tops of the strings and the right leg be placed on the round below the shroud (Fig. 13, *right*). Keeping his weight on the head of the ladder, the man should then swing out, at the same time placing the left foot on the round below the right and straightening the arms. If descending from the right the left leg should be used.

(v) *To Descend Quickly in an Emergency.* The method of making a quick descent by using a line made fast to the head of the ladder and given a round turn through the hook of the hook belt is dealt with in the Chapter on "Methods of Rescue."

(vi) *To Use as a Roof Ladder.* The hook ladder may also be used as a roof ladder (Fig. 14) or "duck-board" when necessary, as when dealing with roof or chimney fires, or to permit the opening of roofs for ventilation purposes at smoky fires. For this purpose the hook of the ladder is placed over the roof ridge and the ladder laid on the roof. This method is specially useful when negotiating sharply raked roofs. As an alternative to the hook ladder for this purpose catwalk ladders have been constructed in some localities. These usually consist of boards across which wooden treads are nailed. One end is secured against a parapet and the ladder laid upon the roof: having treads

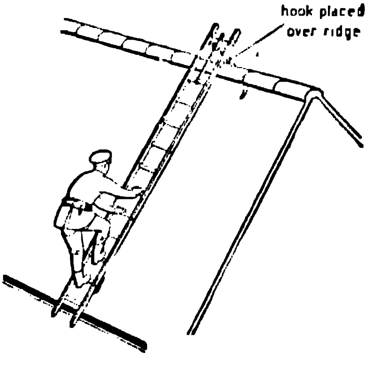


Fig. 14. Method of using hook ladder to climb a ridged roof.

instead of rounds, it is more easily climbed than a normal type ladder.

4. SCALING LADDERS

A scaling ladder (Fig. 15) is a tapering ladder fitted with two steel or gunmetal brackets outside the strings at the head and with two similar brackets inside the strings at the heel for the purpose of shipping another length at either end, each separate length being interchangeable.

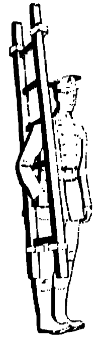


Fig. 15. Scaling ladder, showing method of carrying.

Construction. Each ladder is 6 ft. 6 ins. long and weighs approximately 21 lbs. The rounds are secured to the strings by gunmetal sockets in such a way that they will not rotate. The head is 3½ ins. narrower than the heel of the ladder. It is strengthened by wrought-iron tie rods ½ in. diameter passed through the 1st, 3rd and 6th rounds and secured on the outside of the strings with round gunmetal tapered nuts.

Standard Test. The ladders are tested monthly, after use at fires, or more frequently still if used for drill purposes. Ladders are to be examined regularly, special attention being given to the rounds and sockets, and to the rigidity of the ladders when joined together.

Use. (i) *General.* Scaling ladders are short, light and compact; being readily portable they are easily carried through narrow spaces, doorways, passages and stairways, separately or fitted together as necessary. They are very useful for scaling walls, providing communication between floors where stairways have been burned away, climbing about on roofs, as bridges from one wall to another, as a gangway from fireboats to shore, or for entering ships' holds or manholes. In case of necessity a ladder can be employed as a stretcher for an injured person. This is dealt with more fully in the Chapter on "Methods of Rescue."

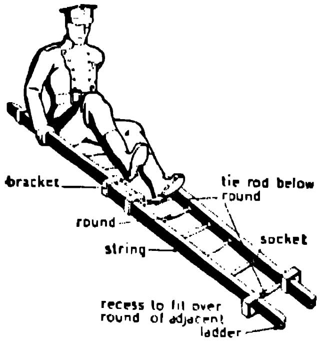


Fig. 16. Method of unshipping scaling ladders, showing also the correct naming of parts.

Each length of ladder when shipped affords an additional 5 ft. 7 ins., therefore five 6 ft. 6 ins. ladders shipped together would produce a ladder 29 ft. long. Normally, not more than five ladders should be shipped together. One man can ship a number of ladders on the ground and can raise the complete ladder by under-running. Ladders if jammed may be unshipped by laying them on the ground and kicking them apart from their brackets (Fig. 16). Where time permits, scaling ladders should be strengthened against separating by means of a line. This is secured by a series of knots known as a yachtsman's purchase, which is described in the Chapter on " Knots and Slings."

(ii) *Lowering*. Scaling ladders are of particular value when it is necessary to employ ladders in a very confined space, for such purposes as lowering into a manhole or ship's hold. This method of shipping is described in the National Fire Service Drill Book.

Certain of the scaling ladders used in fireboats are fitted with special spring clips (Fig. 17) so that when they are lowered into ships' holds it is not necessary to lash them.

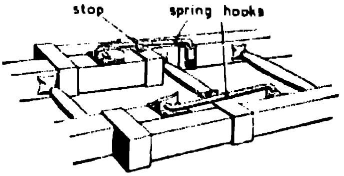


Fig. 17. Interlocking gear used on scaling ladders carried on certain fireboats.

A swivelling spring hook is attached to the inner face of each string between the first and second rounds, its travel being restricted by a metal stop mounted on the socket. The hook is directed, by a curved projection on the head of the ladder below, into a hole with which it engages.

(iii) *Bridging*. To bridge a distance of not more than 9 ft. two ladders are shipped and lashed together at adjoining rounds. A third ladder is then placed centrally above and the ladders are lashed together with lines at points where the upper ladder meets the lower ladders (Fig. 18). For distances of more than 9 ft. up to 12 ft. three lower and two upper ladders are used, lashed in a similar way at all joints and at the ends of the top ladders. The ladders are then turned over (Fig. 19) and pushed or drawn over the gap with the central strengthening ladders below. The bridge thus formed is capable of taking a considerable weight.

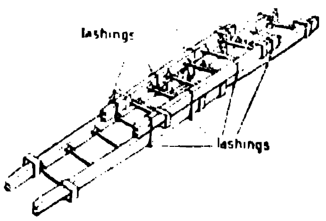


Fig. 18. Method of lashing scaling ladders to form a bridge.

5. POLE LADDER

This is an unusual type of ladder which was used by many fire brigades before nationalisation. It consists of a short ladder of the first-floor type, the rounds of which are hinged by means of a pin through the strings, to enable it to be folded. The strings are channelled so that when they come together the rounds fit into these recesses and the strings lie

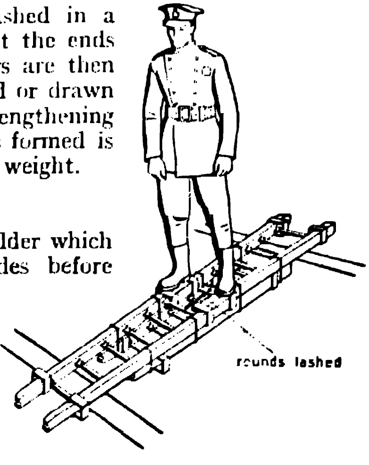


Fig. 19. Bridge formed by lashed scaling ladders.

flat against each other. The folded ladder, which is then secured by a leather strap, has thus the appearance of a single pole. The length of the ladder is 10 ft. 8 ins. when folded, and 9 ft. 10 ins. open.

The advantages claimed for this type of ladder are that not only does it occupy the minimum of space on an appliance, but it can also be used as a battering ram for breaking down heavy doors. Both ends are steel shod to prevent the strings being damaged when the ladder is being used for this purpose.

6. NON-SERVICE LADDERS

It frequently happens that when a ladder is required builder's or other similar ladders are the only ones available. They should be used with care, because time and circumstances may prevent other than a cursory examination before use. They should not be climbed hurriedly, and the weight should be transferred gradually from one round to another, keeping the feet well apart. The heel of the ladder should not be drawn too far from the building as the more perpendicular it is the stronger it is. With this type the rounds are generally spaced at 9-in. intervals.

LADDER WORK

I. HANDLING LADDERS*

The ability to handle ladders and move them from place to place quickly, safely and in an expert manner is an indication of good firemanship.

Practice in the handling of ladders under favourable conditions will give a much higher standard of efficiency when speedy and correct manipulation in difficult conditions is required to save lives and property. It is important that ladders should at all times be handled with care to prevent damage and splintering, and it must be remembered, too, that the incorrect balancing and handling of ladders may cause unnecessary strain and personal injury. When ladders are moved, more especially at night, accidents can often be averted by requiring that the head of the ladder should be painted

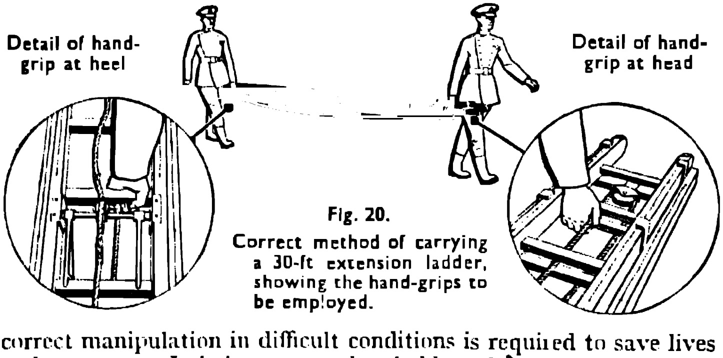

Detail of hand-grip at heel
Detail of hand-grip at head

Fig. 20.
Correct method of carrying a 30-ft extension ladder, showing the hand-grips to be employed.

* The method for a long extension ladder described and illustrated on this page should be used for a long carry only. For other carries and drills, use the method described in the National Fire Service Drill Book (Notes to extension ladder drills).

white to make it easily visible, and that the man or men carrying the front end of the ladder should walk with arm extended to ward off others who might be struck by the ends of the steel-shod strings. It is suggested that the top side only of the head of the ladder should be painted, as the fact that paint is showing will then immediately indicate that the ladder is correctly faced to the building. The correct method of carrying an extension ladder is shown in Fig. 20.

To carry a long and heavy ladder through a narrow gate or passage-way, the men should swing under it in single file and carry the ladder overhead. If four or more men are carrying, then the men on the right-hand side of the ladder will move forward, and those on the left-hand side drop back. The ladder should be held by the rounds with the hands apart and as close to the strings as possible.

2. PITCHING A LADDER

A ladder should always be pitched to the extreme side of a window, normally to the right (unless the wind is blowing smoke and fire to that side). If this has been done correctly a man carrying out a rescue will be able to use his right hand, the stronger and more useful, to grasp the ladder and assist him in lifting the rescued person on to the ladder.

The head of the ladder should be well above the sill of the window (Fig. 21) as it is then easier to step on to when carrying a rescued person. Where the window is narrow the ladder should rest on the wall and not the sill, so that the maximum space is left for working and for entering the building. It is not necessary to secure the head of a ladder by lashing, unless (*a*) the heel of the ladder is on uneven ground, (*b*) the ladder is left unattended for any length of time, or (*c*) when working from a ladder. In cases where the internal staircase of a building cannot be used because of damage, an improvised external staircase can be made by using two extension ladders, side by side, and lashed by the strings at top and bottom ; in this case the heads of the ladders should be secured.

3. PRECAUTIONS IN THE PITCHING OF LADDERS

A long extension (30 or 40 ft.) ladder should not be pitched more than 14 ft. or less than 7 ft. away from the building, depending upon the height of extension. It is advisable to use the greater distance when a branch is to be used from the head of the ladder. It is important that a man should be stationed at the heel of a ladder even though a steel heelplate is fitted to prevent the ladder from slipping. The ladder should be steadied by placing the right foot on the lowest round, bracing the left leg well back, grasping both strings one in either hand, and pressing on the ladder. At no time should more men than necessary be allowed to climb a ladder simultaneously. Three men is the maximum permissible for the largest sizes of ladders. Care should be exercised that the safety overlap of the upper extension with the lower (as indicated by the white safety mark painted on the outside of each string) is not reduced ; this is particularly important when using the short-extension ladders.

4. LADDER CLIMBING HINTS

A ladder should be climbed briskly but smoothly, and the fireman who is to climb ladders well must therefore be agile and possess balance and rhythm. Both are the result of correct instruction and practice and are essential to good firemanship. When a man holds himself rigid and keeps too close to the ladder he does not possess complete control of his body, and his knees are liable to foul the rounds. Balance is achieved by keeping the body erect, the arms straight but not tense, and rhythm by the smoothness of action of arms and feet when ascending and descending.

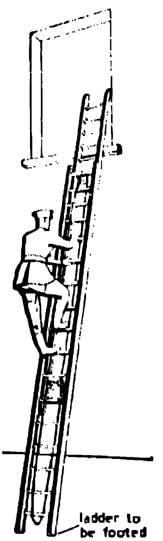


Fig. 21. Correct method of climbing a ladder.

To maintain a steady ladder and steady progress when climbing, the feet should be kept towards the centre of the rounds and placed naturally in what is felt to be a comfortable climbing position. The climber should not watch his feet but should look slightly upwards in the direction of the climb (Fig. 21). The hands should be moved smoothly on the rounds at a level between the waist and shoulders ; operating above shoulder level gives less control and uses more energy. The rounds should be grasped by the hands with the palms down and the thumbs under the rounds. Body sway will thus be avoided and the hands at the same time can test the rounds, so that a defective round is detected before the full weight of the body has been placed upon it. Both hands should never be on the same round at the same time. Should a round break under the feet, a firm grasp with the hands on the rounds is sufficient to prevent a fall. This is not the case when the strings are grasped, since if the foothold is lost the hands will slip. Only in special circumstances, *e.g.*, when using the first-floor ladder as an additional extension to an escape, should the strings of a ladder be used for climbing.

It must be remembered that the legs and not the hands carry the weight of the body when climbing. At each step the ball of the foot, and not the arch, should be placed on the round. When ascending or descending, the hand and the foot on the same side of the body should move in unison, *i.e.*, left hand and left foot, right hand and right foot.

5. BRIDGING FROM A LADDER TO A WINDOW

One man carrying either a section of a short-extension ladder, a scaling ladder, or a first-floor ladder, climbs to the required position and seats himself sideways on a round, facing a string and using a " leg-lock " (see below). The bridging ladder is swung across by placing the inside hand under the lower string and the outside hand over the upper string. The ladder is passed across the space to the window, using the protruding knee as a supporting pivot. The bridging ladder is then lashed to the main ladder.

6. TAKING A LEG-LOCK

When working from a ladder it is frequently necessary to have both hands free to direct a jet, to handle a small ladder, or haul up sundry small gear. A fireman working on a ladder should not release his hold unless he has properly secured himself, preferably by a hook belt or a line. Such equipment, however, is not always readily available in an emergency, and, therefore, a fireman must know the best improvised method of securing himself to the ladder to allow him to work with his hands free. This is easily accomplished by taking a leg-lock on the ladder. To take a leg-lock the man should stand on one round and place the other leg through the ladder over the second round above the round on which he is standing. Then he should bend the leg and use the inside of the knee and back of the calf of the leg for steadying purposes. If the length of leg so permits, it may be possible for him to bring the foot back through the ladder between the rounds and place the toe of the foot under the round above the one on which he is standing. The leg-lock is made on the side of the ladder opposite to the side on which the work is being carried out. The arch of the lower foot should be placed near the strings in a position to prevent it from sliding if the round is wet.

7. TAKING AN ARM-HOLD

When using a branch from a ladder it is a wise precaution to put one hand round a string before grasping the branch, while the other directly holds the base. This procedure should, especially, be followed in cold weather when ice is liable to form on the ladder.

8. CONSTRUCTION OF A STEP LADDER

Step ladders of varying height can be made from ladders normally carried on Fire Service appliances by using—

(*a*) Two 30-ft. extension ladders for a long step ladder.
(*b*) Two short extending ladders for a medium step ladder.
(*c*) The two sections of the short extending ladder for a short step ladder.

A step ladder is required to reach a ceiling or roof where a single ladder cannot be used. The long step ladder is employed to reach the middle of a high ceiling, such as is found in a school gymnasium, hall, etc., where no support for an extension ladder exists.

To make long- and medium-sized step ladders (Fig. 22, *left*) the ladders are extended horizontally on the ground or floor to the required length. One ladder is extended one round more than the other to allow the second ladder to interlock. The head is then lashed securely. The spread of the long ladder at the base should not exceed 7 ft. and of the medium ladder 4 ft. 6 ins. The top section of a short extension ladder can be used as a fixed spreader at the base (Fig. 22, *centre*), in place of a spreader line, by passing the section through the bottom rounds at the base of the two extension ladders, and lashing the adjoining rounds each side with a line. If using a spreader line this is to be attached by a clove hitch to the third round from the bottom of both ladders. The ladders are then raised in the form of a letter " A."

To make a short step ladder (Fig. 22, *right*) the two sections of a short extension ladder are separated and the top extension is interlocked at the head of the main extension. The head is then lashed as for the long and medium step ladders. The spread at the base should not exceed 3 ft. 6 ins. and the spreader line is tied as for the long and medium step ladders.

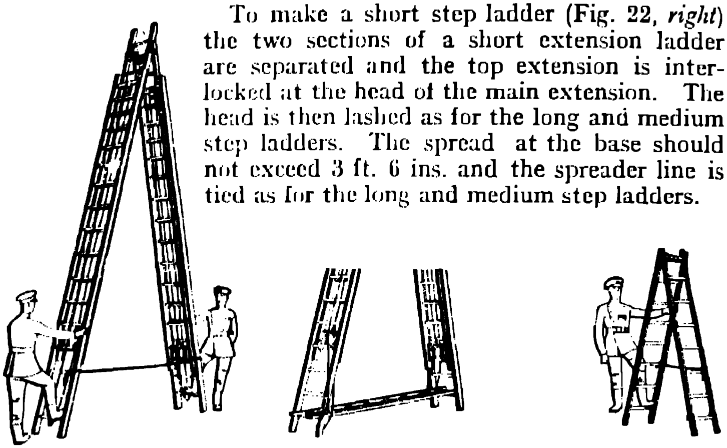


Fig. 22. Left : method of constructing a step ladder, using two 30-ft. extension ladders, showing rope used as stretcher. Centre : method of strengthening the base of a step ladder using a section of the short extension ladder as a stretcher. Right : method of constructing a step ladder from the two sections of a short extension ladder.

Two men should foot the long step ladder for steadying purposes, but only one man is required to foot the medium and short step ladders.

MAINTENANCE

Apart from the regular testing of ladders, the punctual and efficient performance of which is of the utmost importance, the following hints on maintenance should be borne in mind.

(*a*) Ladders of all types should be used regularly at drills in order to keep them in shape. They should not be stored in one position or warping is likely to result.

(*b*) The wood of ladders is liable to splinter, and any roughness or incipient splinters should be sandpapered off, or, if the ladder is badly affected, it should be sent to the workshops for scraping down and recoating with preservative.

(*c*) When the preservative, whether varnish or not, becomes worn, it should be replaced immediately, otherwise the weather may reach the wood and affect its strength.

(*d*) Repairs should only be carried out by experts, and should not be attempted by those unacquainted with the structure of ladders.

PART I CHAPTER 7

ROPES AND LINES

ROPE making is one of the oldest industries practised by man and its origin is lost in antiquity. It is, however, known that the ancient Egyptians possessed the art with a high degree of skill, for when the doors of the inner chamber of the tomb of Tutankhamen were opened it was found that they had been secured by a length of 4-in. rope. The quality and the workmanship shown were of a high order, so that the industry goes back well over 3,000 years.

There has been considerable uncertainty, particularly among students, of the meaning of such terms as " Hawser," " Cable," " Rope," " Line," etc. These terms, although generally and indiscriminately used by laymen, have precise meanings which should be clearly understood before any instruction is given or taken in this subject.

In order to standardise the use of such terms throughout the Service a glossary of terms has been prepared, which will be found at the end of this chapter.

CONSTRUCTION

I. MATERIALS

Ropes may be either of metal or fibre or sometimes of mixed construction, though in the latter case it is the metal part which carries the load. Fibre ropes as described here may be considered as being ropes other than steel wire ropes and may be manufactured from a number of different types of vegetable fibres.

Rope as generally used in the Fire Service is made principally of :—

(*a*) Italian hemp.
(*b*) Manila.

and to a much lesser extent of—

(*c*) Sisal.
(*d*) Coir.
(*e*) Cotton.

Italian hemp is normally considered to be the best for Fire Service work as it is less likely to swell when wetted and, owing to the softness of the fibres, is more flexible, can be used over shorter radius curves and therefore has a longer life.

Manila, on the other hand, is an excellent general purpose rope, is less expensive, and can now be made practically waterproof.

Sisal, though approximately as strong as manila, is not normally used, since it swells considerably when it is wet and is liable to be slippery. Coir, owing to its lightness, will float on water and is used in the River Service for getting lines of hose and warps (*i.e.*, lines used for mooring vessels) ashore. A great advantage is its elasticity, but it has not the strength of the preceding types.

Cotton rope also has a high resilience and is soft to handle.

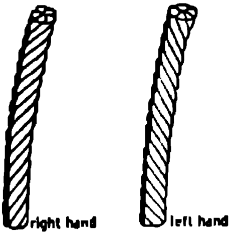


Fig. I. Sketch showing right-hand and left-hand lays.

Internal wear due to bending is slight and the external appearance therefore gives a better indication of the actual state of the rope than with other types. It has, however, a very short staple, and is therefore very susceptible to damage from chafing.

2. METHOD OF MANUFACTURE

Hemp, manila and sisal are all received at the rope works in bales ; the fibre being ready for making into rope. The first process or " preparation " of the fibre consists in combing it on a series of special machines so that the individual fibres are arranged roughly parallel. In this state it is known as a " sliver." The next process consists of " spinning," in which a permanent twist is mechanically imparted to the sliver, then known as a " yarn," which is wound automatically as it is produced on to bobbins. When the yarn has been prepared it is subjected to one or other of two processes depending on whether a " laid " rope or a plaited rope is desired.

3. LAYING·

After spinning, the bobbins filled with yarn are ready to be made up into " strands." These strands, which consist of a series of yarns twisted together, are made up in one of two ways, either in a " rope walk " or by a special form of machine. The former is still largely employed for making fibre ropes and in its essentials differs little from the method used for centuries. The rope walk consists of a long narrow shed which may be as much as 1,200 ft. long, since rope cannot be made by this method in one piece of a greater length than that of the walk. Rope is normally made in lengths not exceeding 120 fathoms or 720 ft. The appropriate number of yarns are drawn off the bobbins and twisted together on the rope walk to form a strand. Three or four strands are thus formed and then twisted together to form the rope. This operation is known as " laying." When laid up, the finished rope is ready for coiling. In order to prevent a rope from unravelling, the yarns making up

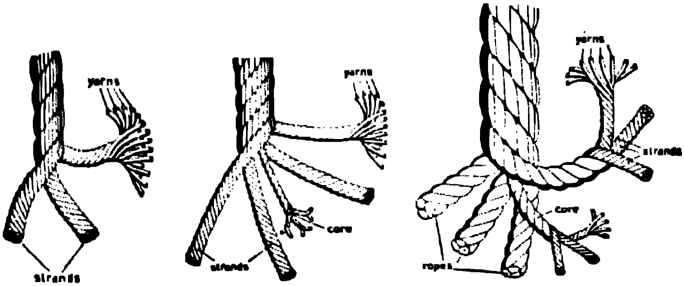


Fig. 2. Sketches showing the construction of (left) hawser-laid rope, (centre) shroud-laid rope, and (right) typical three-strand four-hawser cable.

the individual strand are twisted together in the opposite direction to that in which the strands are twisted when made up into rope. Rope may be " laid up " either right hand or left hand, and is then known as having a " right-hand " or " left hand " lay respectively. The lay can be determined by looking at the rope ; if the strand runs away from the body from left to right, it is a right-hand lay, if from right to left then it is a left-hand lay (Fig. 1). A hawser-laid rope is made up of three strands laid together (Fig. 2, *left*), whilst shroud-laid rope (Fig. 2, *centre*) consists of four strands laid together, usually around a central core. A cable-laid rope (Fig. 2, *right*) consists of three or more hawser-laid ropes, with or without a central core. A cable is usually laid up left-handed since the individual hawsers of which it is constituted are laid up right-handed.

4. PLAITED ROPE

Rope used for certain purposes such as the life lines with which emergency turntable ladders are equipped, may be of plaited construction. In this there is a central core around which the yarns are plaited in the normal manner (Fig. 3). To avoid undesirable distribution of stress in the rope the central core is made up of short strands and acts as a " former " only. It does not play any part in taking the load on the rope. This line is somewhat less strong, size for size, than the ordinary right- or left-hand laid rope but possesses the definite advantages that it is more flexible, is less likely to kink and does not expand to any marked extent when wetted. Undue wear can also readily be detected by an unskilled person since, if one of the threads of which the rope is made should break, the ends immediately show up.

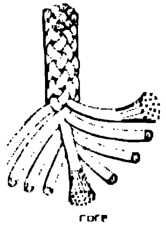


Fig. 3. Sketch showing the construction of plaited rope.

Rope purchased by the Government for general use is governed by specification No. T.G.30. Some departments, in order to identify their rope, arrange for a coloured yarn to be inserted. This, for obvious reasons, is known as a " rogue's " yarn.

The British Standards Institution have framed a Specification governing the construction of manila ropes (B.S.S. 431) and have laid down certain definitions. A few of these will be found in the Glossary at the end of this chapter.

A handy guide to the use of rope, particularly in connection with lifting tackle, is published by the Hard Fibre and Cordage Federation, Portland House, 73, Basinghall St., London, E.C.2., entitled " Lifting Tackle—Schedule and Code of Practice to assist Users to comply with the Provisions of the Factories Act, 1937, Section 23."

MAINTENANCE

Since rope is a vegetable fibre, much the same remarks apply with regard to care and maintenance as were made under the heading in Chapter 4. Deterioration may be caused in one or other of two ways, 1. Mechanical, 2. Chemical.

1. MECHANICAL DETERIORATION

This is caused through wear or internal friction. It is essential therefore to avoid anything which will add to this. Rope should be uncoiled carefully to avoid kinking, starting at the bottom on the inside of a coil, working anti-clockwise. After the line has been uncoiled, kinking is still possible and steps must therefore be taken to see that this does not arise. Kinking tends to draw the fibres apart and weakens them, therefore strain should not be applied to a rope which is kinked.

Sharp bends should be avoided, particularly when securing the end of a line. When lowering a weight, the line must not be allowed to chafe on a sharp edge such as a coping. Dragging along the ground drives grit into the fibres and subsequent internal movement between the strands will cause the grit to cut into the fibres and seriously weaken them. If a rope becomes very dirty it should be washed and allowed to dry in the same way as for canvas hose. When rope must change direction under strain it should be passed through a pulley block, but the sheave of the block must be sufficiently large to accommodate the rope so that it does not ride on the shoulders. If the sheave is too narrow, more damage may be done than if a block had not been used. Rope should not, if avoidable, be led round bends when under strain but should be so arranged that as direct a pull as possible is obtained. When sharply bent under strain the total stress is unevenly distributed amongst the individual fibres and hence the rope is weakened.

2. CHEMICAL DETERIORATION

This may be caused by exposure to acids, alkalis, weather conditions or by submersion in water for any considerable time. Therefore rope should be stored, as far as possible, in a cool dry place with plenty of ventilation. It should never be stored damp, or mildew will set in. Nor should it be stored directly on the floor, but on boards raised above ground level. The coils should be turned over from time to time. The ideal temperature of a rope store is between 56° and 70° F. with a humidity of between 40 and 65 per cent. Rope, like hose, is more liable to damage when wet, therefore, as far as possible, it should be kept dry, particularly when in use.

The higher the grade of fibre used in the rope the less is the detrimental effect of damp and moisture, consequently the expectation of life is higher for a better grade rope than for one of a poor quality.

Rope is sometimes treated with Stockholm tar (obtained from wood) to prevent mildew due to damp. This may be effected by introducing the tar into the fibre before spinning or subsequently, after the rope is made up, by boiling. The latter method weakens the rope and tarred ropes are always considered to have a lower breaking strain than untreated ones.

Wet or damp ropes should not be thrown on the ground and left there as this will cause the fibre to rot. Frequently the rot commences from the inside of the rope and cannot be detected by external examination, therefore the greatest care should be exercised to avoid contamination of this description. Rope which has become wet should be dried out naturally, for if it is dried artificially and too rapidly the fibres become brittle and the rope loses strength. It should not be kept in the bright sunlight, as the rays of the sun produce an action which discolours the fibres and weakens both manila and sisal. It should never be left in contact with iron since rust is a potent cause of deterioration. Most acids and alkalis will cause burning and destroy the strength and shorten the life of the fibre. Even fumes in certain cases have this effect.

TESTING

Since the safety of a person may frequently depend on the strength of a rope it is essential that all ropes used by the Fire Service should be adequate for the work which they are designed to carry out, and that they should be tested and inspected frequently to ensure that they are in first-class condition.

The following standard tests for lines were in force at the date of publication of this *Manual.*

> " Ropes and lines are to be tested monthly, after use at a fire and, in the case of lines used for lowering, before use for drill. All lines are to be examined and lowering and other similar lines are to be tested by securing at one end and a steady strain of six men applied."

Jerking a line should not be allowed whilst testing, since it subjects it to unpredictable strain and is not a true measure of its strength. When the rope is being inspected care should be taken to avoid distortion. Points to be watched are that external chafing and cutting are absent and that there is no internal wear between the strands. It is of the utmost importance to verify that no deterioration of the fibre has set in and, when lines are tested, to see that all fittings such as swivels, snap hooks, etc., are free from defects.

The Admiralty, in the Manual of Seamanship, 1937, Volume I, Chapter 3, page 95, give the following method for ascertaining the breaking, proof and safe working load in tons, of hemp rope up to 6 in. size—" Square the size of the rope and divide consecutively by 3, 9 and 18." For a 2-in. rope, for instance :—

$$\frac{2^2}{3} = \frac{4}{3} \text{ tons} = 26\tfrac{2}{3} \text{ cwt. (approx.) breaking strain.}$$

$$\frac{2^2}{9} = \frac{4}{9} \text{ tons} = 9 \text{ cwt. (approx.) proof (testing) strain.}$$

$$\frac{2^2}{18} = \frac{4}{18} \text{ tons} = 4\tfrac{1}{3} \text{ cwt. (approx.) safe working load.}$$

These figures give a considerable margin of safety, since the 2-in. manila rope manufactured to Government specifications has a normal minimum breaking strain of 35 cwt. and a safe working load is 5 to 5½ cwt.

British Standard Specification No. 431 states in the foreword :—

" For new ropes employed for lifting purposes, a ratio of maximum dead working load to guaranteed breaking load of rope of not less

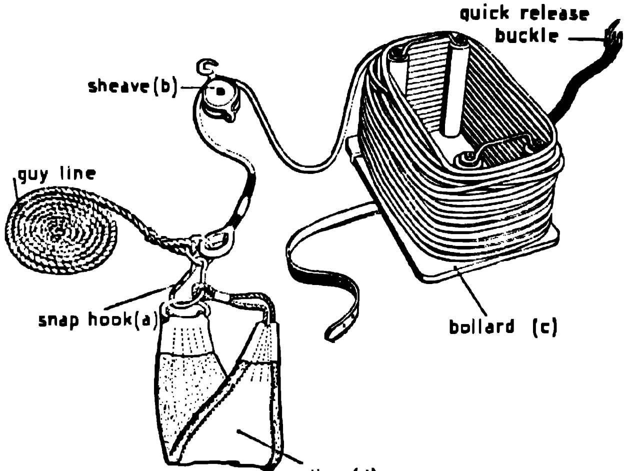


Fig. 4. Close-up view of sling, spring snap hook, sheave and wooden bollard for extra long life-line used with certain turntable ladders.

than 6 is recommended. The factor of safety employed should be considered together with the conditions of service and the condition of the rope, and while 6 is recommended as a minimum for new rope, it is, in many instances, desirable to increase this substantially, *i.e.*, to 7 or 8, where the conditions are adverse and warrant such a course being taken."

Rope makers recommend that where the necessary facilities are available, rope should be tested by running it through a single sheave pulley block at the head of a tower and suspending a weight equivalent to the required test. Thus for a 2-in. manila rope, a half-ton weight would be attached to the bottom and the weight drawn up by a number of men until it is clear of the ground.

LINES IN USE IN THE SERVICE

Cordage forms an essential part of Fire Service equipment. There is hardly an operation in firefighting, whether it be effecting a rescue, getting a length of hose up a building, strengthening a ladder, or making fast the suction when working from open water, which does not call for the use of a rope or line.

The lines mentioned below will be found on the majority of appliances throughout the country. Every Fire Service appliance should carry at least one long line and one short line, though the materials from which these are made and in some cases the lengths may differ slightly according to locality.

I. EXTRA LONG LIFE LINES

Used on turntable ladders (Fig. 4). The length varies with the type of ladder on which it is carried, but is usually between 200 and

230 ft., 2 in. circumference, made from plaited Italian hemp, or sometimes of plaited cotton, and fitted at one end with a mild steel spring snap hook (*a*).

Before the line is made up it is rove through a galvanised iron sheave (*b*), which is then drawn to the end of the line until it rests against the spring hook.

The line is then coiled down on a wooden bollard (*c*) to which one end is permanently secured. Alternatively the line may be wound on a large wooden reel, the axis of which is extended at each end to form a handle. The free end of the line, with the hook and sheave, in the former case, is stowed in the centre of the coil, where it is ready for immediate use.

The line is carried on the appliance either in a clip behind the driver's seat, or, if the ladder is fitted with a revolving turntable platform, the bollard may be carried there.

The use of this line, and of the canvas safety belt or sling (*d*) which comprises an essential part of the rescue equipment, is fully described in the Chapter on "Turntable Ladders."

2. LOWERING LINES

The length of these lines varies in different localities, but is usually specified as not less than 130 ft. It is not unusual to find that certain appliances on whose station ground high buildings occur, carry extra long lowering lines. Lowering lines may be hawser-laid of Italian hemp 2 in. circumference or of plaited construction of much the same size.

As the principal use of the line is for rescue work, it may either be made up with two legs at one end or it may terminate in a snap hook with or without a swivel. In the case of the former type (Fig. 5, *left*) each leg is fitted with a running eye, the lengths being so adjusted that the two bights permit of a body being placed in them and lowered.

These legs are made by splicing in an additional 7 ft. of line (*a*) about 6 ft. from one end. This provides two legs, the shorter of which (*b*) is the standing part, and is indicated by a Turk's head knot (*c*) worked round it just below the splice, so that it can readily be identified by touch in the dark. The fact that one leg is shorter than the other allows the person being lowered to assume as comfortable a position as possible, with his head upright. It is important,

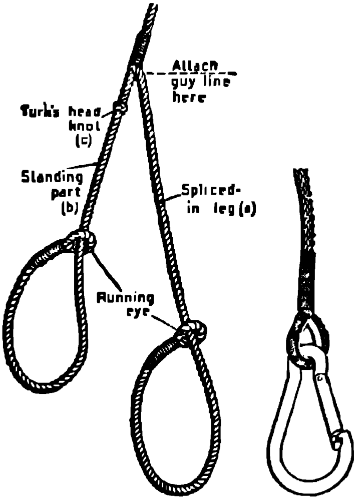


Fig. 5. Left : hawser-laid lowering line with spliced-in leg fitted with running eyes. Right : spring snap hook fitted on a plaited lowering line.

therefore, that the shorter leg should be made from the standing part, as it is this end which is passed round the body under the arm-pits.

If the shorter leg were made from the length spliced in, and the splice were to part, the person being lowered would be suspended head downwards by the standing part round his legs, and a serious accident might result. If, on the other hand, the line is properly constructed and the splice gives, the person being lowered is still securely held head uppermost. A plaited type line fitted with a snap hook is illustrated in Fig. 5, *right.*

A guy line, approximately 130 ft. long, is used in conjunction with both types of line. This may be kept permanently attached or may be a bobbin line bent on by means of a clove-hitch one half of which is made above and the other below the splice, on the standing part, or by means of a couple of turns and by securing the guy line on itself by means of the snap hook. The guy line is thrown down, and used by the men below to keep the rescued person clear of the building while he is being lowered.

Lowering lines, being primarily rescue lines, are usually carried externally on the carriage of the escape, or some other accessible position. They are sometimes made up on a special leather cradle, but more commonly on a wooden bollard. Methods of making up the lines described in the Chapter on " Knots and Slings " vary, some American brigades, for example, use a method similar to the blood knot used for making up belt lines, which provides a loop for carrying the line over the shoulders, and an immediate pay-out when thrown down. Whatever method is employed, a lowering line should always be made up and stowed so that it is ready for immediate use in any emergency.

It is not unusual to mark the centre of a lowering line with a binding or a Turk's head knot which should preferably be of another colour to facilitate easy recognition. The use of the lines is fully described in the chapter on " Methods of Rescue." Italian hemp lowering lines, as used in one locality, showed on test breaking strains of around 2·8 tons for a 2-in. rope.

3. LONG LINES

Long lines are general purpose lines, 100 ft. in length and 2 in. circumference, made from untanned manila having plain " whipped " ends. They are used for a variety of purposes, the most common being to haul a length of hose aloft. They may also be found useful for the purpose of roping off streets or areas on the fire ground to hold back spectators. They should not be used for rescue work except in an emergency when no lowering line is available. When new they have a test breaking strain of approximately 35 cwt. They should be carried in a convenient locker, made up as described in the Chapter on " Knots and Slings."

4. SHORT LINES

Short lines vary between 40 and 50 ft. in length, and in most localities consist of 2-in. untanned manila identical with the long line described above. Short lines have, however, been made in many localities by cutting out the sound parts from condemned lowering lines. Short lines of varying material and length may, therefore, be found in use.

The short line is used for innumerable small jobs for which the long line would be unnecessarily cumbersome, the most common being to make fast the strainer and suction when working from open water. It is also usually more convenient for strengthening scaling ladders or lowering them into holds or basements, etc., as there is less line to pull clear at each stage of the operation.

The line should be stowed beside the long line, made up as described in the Chapter on " Knots and Slings."

5. ESCAPE LINES

An escape line is a line between 15 and 20 ft. in length secured to the top round of an extension ladder or escape by means of a running eye, the free end of which is taken into the building to assist men to find their way back to the window from a smoke-laden room. It may also be used for securing the head of an extension ladder.

There is no specified material or size for escape lines, but as they are commonly made from condemned lowering long or short lines they may generally be stated to be 2-in. lines made from either Italian hemp or untanned manila.

An escape line will be found on most escapes, extension ladders, etc. It is often secured by means of an eye attached to the top round with a snap hook attached to the end for clipping the rope to itself when securing. When not in use it is coiled and secured by metal clips, but in some areas is allowed to lie along the strings of the ladder where it is ready to hand at all times. When arranged in this way care must be taken to see that it does not foul the extensions as they ride over one another when extending or lowering.

6. BOBBIN LINES

The bobbin line is a light line, approximately 130 ft. in length, and made from 2½ lbs. brown thread, used on hook belts. It takes its name from the fact that it is wound on a leather bobbin (Fig. 6) rather like a large cotton reel (*a*), carried in a special pouch (*b*) on the hook belt, with the opening underneath, so that when the catch is released the weight of the bobbin causes the line to fall out into the fireman's hand ready for use.

After the line is made up on the bobbin the free end, which is fitted with a swivel and snap hook, is attached to a " D " ring on the hook belt (*c*). One end of the line is thus always secured, so that the bobbin need only be cast away and the line will pay itself out, leaving both hands free for other work.

The bobbin line is used for hauling light gear aloft, for bringing up a heavier line or as a guy line. It is almost invariably found on hook belts used in conjunction with hook ladders or turntable ladders.

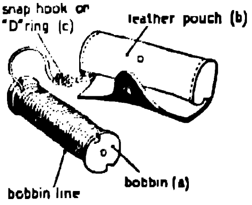


Fig. 6. Bobbin line and pouch as carried on a hook belt.

7. BELT LINES

Sometimes known as " pocket " lines or " sennet " lines. These are in general use in almost all localities, but their exact length and composition vary considerably.

One type of belt line, as issued prior to nationalisation, was made up in 12-ft. lengths of 3 strands, 12 yarn, 60 threads having a weight of between 4 and 8 lbs. per 300 ft., with a breaking strain not lower than 460 lbs. In other areas they are 40 to 50 ft. long (sennet lines) and used for hauling up small gear. Belt lines are used for a wide variety of purposes, including lashing branches, etc. Their strength is such that they can be used in an emergency for rescue purposes when knotted together.

The belt line, as its name implies, is usually carried on the fireman's belt, made up as described in the Chapter on " Knots and Slings." The line should be worn on the left side of the belt, between the buckle and axe-pouch.

8. HEAVING LINES

Heaving lines, 80 to 100 ft. in length, made from the same material as belt lines, are fitted with a weight at one end, usually a partially filled small sandbag.

They are used for casting a field telephone line over standing cables on the side of the road and are carried on field telephone vans.

9. COIR, OR GRASS LINES

These are issued to River Service craft in 120 fathom lengths (720 ft.). They are made of coir, which, owing to its lightness, floats on the surface of the water and is therefore ideal for use on river craft.

The ends of the line are spliced together to make an endless whip, which is used for hauling lengths of hose ashore. The line is passed round bollards, or through pulley blocks placed one forward and one aft and the bight taken ashore. Hose can then be brought either to the shore or the boat by hauling on the line. It is of interest to note that minimum breaking load under the Government Specification for hawser-laid coir cordage is 7 cwt. for a 2-in. hawser as compared with 35 cwt. for a similar size manila hawser.

A variety of warps or mooring lines are used by the River Service. No standard lengths or measurements can be given, as it is usual for coils of various sizes to be issued and cut as required.

Manila, hemp, coir, and, occasionally, cotton lines of all sizes from ½ to 4 in. circumference, and any length from 10 to 40 ft., will therefore be found in use for mooring river craft.

Lines used by the River Service are not made up on cradles, but coiled down either on the deck or in lockers.

Whilst considerable variation in the types of lines in use may occur, the majority fall into one or other of the above categories, though differences in material, lengths and methods of making up may be encountered.

GLOSSARY OF ROPE MAKING TERMS

Cable Laid. Made up from three or more hawsers laid in the opposite way to the strands of the hawsers.

Cable. A cable-laid rope. The term is misleadingly applied to many types of large ropes, but should only be applied to a rope made by laying together three or more hawser-laid ropes.

Cordage. The description applied to all forms of rope, lines and twines and usually meant to cover the whole of the title " rope requirements."

Hawser-laid. Made from three strands, laid up in the opposite direction to the lay of the strands.

Hawser. A hawser-laid rope. The term is generally used, particularly at sea, to indicate large ropes of 6 in. circumference and over. The true definition is " a rope consisting of three strands, laid up in the opposite way to the strands." As strands are commonly laid up left-handed most hawsers are laid right-handed.

Lay. The manner in which yarns, strands or ropes are twisted together to form larger units of cordage. The lay of a rope can be determined by looking at the direction taken by the strand—if it runs towards the right it is a right-hand lay, if towards the left it is a left-hand lay.

Line. Cordage cut to a specified length for a particular purpose, viz. " Lowering Line," " Life Line," " Belt Line." The term is derived from the use of ropes at sea, and is commonly used to distinguish between the manufacturers' product in bulk (*i.e.*, 120 fathoms of 2-in. manila, etc.) and the lengths which are cut from it.

Rope. The composition of six or more yarns formed into three or more strands, that is to say, not less than two yarns are taken and twisted together to form a strand, and of these strands three or more are taken and laid together to form a rope. Rope cannot be made in any size smaller than ½ in. circumference consisting of a total of six yarns made up in three strands. (B.S.S. 431.)

Shroud-laid. Made up from four strands and a central core, usually laid right handed.

Size. The size of a rope is always expressed in terms of its circumference (B.S.S. 431).

Sliver. The first stage in the spinning of yarn. Consists of a continuous broad band (up to 3 in. wide) of fibres which have been arranged roughly parallel by a combing process.

Strand. An intermediate stage in rope construction, made by twisting together two or more yarns, usually left-handed. Three or four strands are laid up, usually right-handed, to form a hawser or shroud-laid rope respectively.

Thread. The smallest divisible part of plaited rope. The smallest unit of cordage.

Twine. Two or more yarns twisted together, usually made from soft hemp or jute, although a certain quantity is made from manila or sisal. Of the latter sisal is usually used for packing purposes, whilst manila is used for making net for the fishing industry. The twine can be finished, that is to say, polished, or unfinished (B.S.S. 431).

Yarn. The smallest divisible part of a laid rope, made by twisting a sliver of hemp, manila or other fibre. Two or more yarns laid up together form a strand.

PART I CHAPTER 8

HAND AND STIRRUP PUMPS

THE earliest appliance in anything like general use for directing a jet of water on to a fire was a form of squirt (Fig. 1) rather like a garden syringe. This was made to hold up to 3 gallons, the body being held by one or two men whilst a third forced home the plunger. These squirts were crude in the extreme and only capable of producing an intermittent and very unsatisfactory jet. As the principles of pump construction became better known, hand pumps were developed in a number of forms. Larger types requiring more than one man for operation developed into the manual fire engines, which were superseded when mechanical power became available and revived again in the two-man manual. The smaller types were improved to deal efficiently with minor fires requiring only limited quantities of water for their extinction. It is with this latter type of pump that this chapter will deal.

THE HAND PUMP

(*a*) *Construction.* Prior to the introduction of the stirrup pump a small hand pump had formed part of the standard equipment of almost all peace-time appliances. Very little alteration has been made in its design for many years past and it is only now being superseded to some extent by the stirrup pump.

A typical example (Fig. 2) is single-acting, having one inlet or foot valve (*a*) and one delivery valve (*b*). It has a double casing, the space between the inner (*c*) and outer (*d*) casings serving as an air-pressure chamber to maintain a continuous stream of water.

The piston (*e*) is formed from two leather cup washers secured to the end of the plunger rod by means of a nut.

Water is expelled through a discharge pipe (*f*) which is connected to the upper or lower end of the outer casing. This discharge pipe has a male screw thread to which is connected one or more lengths of $\frac{5}{8}$-in. rubber-lined canvas delivery hose. A $\frac{3}{16}$-in. nozzle is fitted to the end of the hose which throws a jet to a height of about 30 ft. These pumps must be held in the water when pumping and to facilitate operation are sometimes fitted with a stirrup similar to that employed on the emergency type hand pump.

(*b*) *Operation.* When the piston moves upwards (Fig. 2, *left*) the foot valve (*a*) opens and water enters the barrel of the inner casing through the strainer holes (*g*). As the piston descends (Fig. 2, *right*) the foot valve closes, the delivery valve opens and water flows from the inner barrel into the outer casing. From the outer casing most of this water escapes through the discharge pipe, but a certain quantity rises higher than the opening of this pipe and compresses the air in the upper part of the

Fig. 1. Drawing of a hand squirt about the time of the Fire of London.

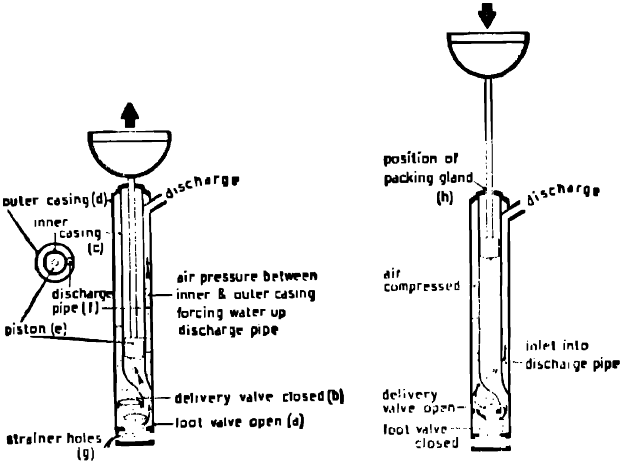


Fig. 2. Left : section through typical hand pump showing valve positions on the upstroke. Right : section through typical hand pump showing valve positions on the downstroke.

casing. On the reverse stroke when the inner casing is being recharged this air expands to its original volume and forces the water out of the discharge pipe, thus giving a relatively steady jet.

(*c*) *Maintenance and Testing.* To dismantle the pump, the packing gland (*h*) is unscrewed and the piston withdrawn from the cylinder. Access to the inlet and delivery valves is obtained by unscrewing the strainer box at the base of the pump.

When the pump has been used it should be dismantled and all water drained from the cylinder by pressing up on the spindle of the delivery valve. The whole pump should be cleaned and the leather piston washers well greased to ensure easy working.

Before the pump is put away it should be tested by placing a finger over the discharge pipe and the piston pressed sharply down. The compression of the air in the cylinder should cause the piston to rise again.

(*d*) *Use.* These pumps are used on small fires and in particular on chimney fires.

THE STIRRUP PUMP

(*a*) *Construction.* To meet the danger of the large number of fires which would be started by incendiary bombs, the Government decided on the policy of providing in large numbers, a small hand pump which was simple in operation and would not break down in the hands of inexperienced operators. It was necessary, therefore to produce a pump which :—

(i) had as few moving parts as possible,

(ii) avoided incorporating any parts which would be subject to wear when put to continual use.

The factor governing the size of the pump is its primary use, *i.e.*, the extinction of small fires using the minimum of water.

A standard basis has therefore been adopted (British Standard Specification A.R.P. 33) for the design of a simple pump (Fig. 3) (operating on the bucket and plunger principle (see part 2, page 6)) in which there are only three moving parts (Fig. 4).

(i) The plunger rod (*a*).

(ii) A ball which forms the foot-valve (*c*).

(iii) A ball which forms a non-return valve (*f*) in the piston (*b*) at the base of the plunger rod.

The only part of the pump which is subjected to any appreciable wear is the packing of the gland (*j*) at the top of the pump casing. This packing usually consists of a piece of oiled string, and if a leakage occurs at this point which cannot be remedied by tightening the gland nut, it is only necessary to replace the packing with another piece of oiled string.

The outlet at the top of the pump casing is connected to a 25 to 30 ft. length of ½-in. bore rubber tubing at the end of which is fixed a dual-purpose nozzle. This nozzle is readily converted by a simple slide mechanism to give either a jet or a spray. In the " jet " position it will throw a ⅛-in. jet approximately 30 ft. and in the " spray " position a fine spray approximately 15 ft. This nozzle is, however, now being superseded by a nozzle giving a jet only. A stirrup is attached to the pump and when not in use the hose is coiled and secured by a strap.

(*b*) ***Operation.*** The hose is uncoiled and the pump casing placed in a bucket of water or other suitable container with the stirrup outside on the ground. The operator holds the pump in position by placing his foot on the stirrup and proceeds to pump. To obtain a solid stream of water and to avoid the pulsating effect which is noticeable with this type of pump, it is recommended that short quick strokes be used instead of the long slow ones which are used when operating, for example, a car tyre pump. The normal rate when using the jet is about 70 double strokes per minute which gives a delivery of 1 to 1¼ g.p.m. and 35 strokes per minute when using the spray giving about ¾ g.p.m. The internal working of the pump is shown in Fig. 4.

When the plunger rod (*a*) and the piston (*b*) attached to the plunger rod moves upwards (Fig. 4, *left*), the foot-valve (*c*) opens and water enters the barrel (*d*) through the strainer cover (*e*); at the same time the ball valve (*f*) in the piston closes and any water above the piston in the working barrel flows out through the discharge pipe (*g*). On the downward stroke (Fig. 4, *right*) the foot-valve (*c*) closes, the ball-valve (*f*) in the piston opens, and a quantity of water enters the upper part of the working barrel (*d*), part of which is forced into the discharge pipe (*g*), the amount being equal to the displacement caused by the plunger rod (*a*).

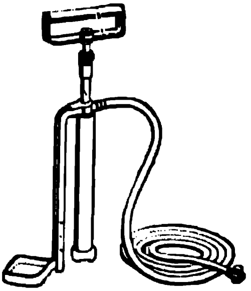


Fig. 3. View of typical emergency-type stirrup pump.

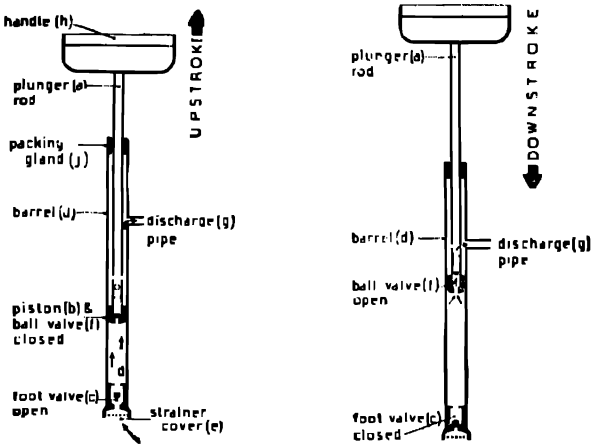


Fig. 4. Left: section through stirrup pump on upstroke showing path of water. Right: section through stirrup pump on downstroke showing path of water.

(c) Maintenance and Testing. If the pump fails to deliver water this will generally be due to one of four causes :—

(i) Choked strainer cover (*e*).
(ii) Ball valves (*c*) and (*f*) seated in through lack of use.
(iii) Rusted ball valves (*c*) and (*f*).
(iv) Choked nozzle.

A choked strainer cover can be cleared by removing the pump from the water and scraping away any dirt which has accumulated. This is a common fault where the pump is operated from dirty water, and care should be taken to see that all buckets used in conjunction with stirrup pumps are free from such articles as cigarette ends, leaves, etc. The ball valves sometimes become stuck to the seats through lack of use. This can often be remedied by turning the pump upside down and pushing a pin or piece of wire through the gauze filter. If the ball is too firmly fixed, remove strainer and lever up with a thin stick. If this fails to dislodge the stuck ball, the pump must be dismantled as described below.

Rusted ball valves constitute the biggest failing in this type of pump. The balls, when made of steel, rust very quickly if the pump is not used at regular intervals ; with the result that the valves fail to operate. To remedy this it is necessary to dismantle the pump and scrape the steel balls with a pocket-knife. The pump is dismantled by first unscrewing the strainer cover (*e*). The handle (*h*) is then removed by unscrewing the retaining nut and the plunger is withdrawn through the lower end of the barrel (*d*). It is not necessary to interfere with or alter the adjustment of the packing gland when withdrawing the plunger rod.

Choked nozzles can be cleared by unscrewing the nozzle and removing any dirt which has collected behind the " jet or spray " holes.

After the pump has been examined for the above faults it should be subjected to a short pressure test. This will show whether the connections between the pump and the hose and the hose and the nozzle are satisfactory. Any signs of a leakage at these points should be rectified by tightening the collars or retying the wire. If water oozes from the gland at the top of the barrel this may be remedied by—

(i) Screwing down the collar until the leak ceases; or

(ii) Replacing the packing with a new length of oiled cord or string.

The pumps should be tested at fortnightly intervals, and regular use is beneficial. They should not be used with liquids such as disinfecting fluids, creosote or whitewash which might set up corrosion inside the pump or perish the rubber hose.

(*d*) *Use.* These pumps can be used to extinguish any small fire for which water is suitable.

BUCKET MOUNTED PUMP

(*a*) *Construction.* This type consists of a single- or double-acting pump, fitted with a suitable length of hose with nozzle, rigidly mounted in a metal water container having a capacity of about 2 to 3 gallons, though larger sizes may sometimes be found. The pump is usually similar in general construction to the hand pump or the stirrup hand pump already described. The water container may be of copper or heavily galvanised iron.

(*b*) *Operation.* The container is filled with water through the filler hole and the pump operated in the normal manner, one man operating the pump, one man taking the hose and nozzle and one man replenishing the water as necessary. In the case of a small fire requiring only a small quantity of water, one man only can operate the device holding the nozzle in one hand and pumping with the other.

(*c*) *Maintenance and Testing.* This is the same as for the appropriate type of hand pump, but the container should be cleaned out and dried after use to prevent the onset of rusting or corrosion.

(*d*) *Use.* These pumps are employed in the same manner as the other types of hand pump but are not widely used by the Fire Service. Their principal advantage is stability in operation with reduced likelihood of upsetting the bucket whilst at work. Their disadvantage is size and the fact that either the container must be filled at the nearest water supply and then carried where wanted, or water must be brought up in separate buckets.

KNAPSACK TYPE PUMP

(*a*) *Construction.* This device consists of a tank having a capacity usually of 4 to 5 gallons, which, by means of suitable straps, can be slung on the back after it has been filled. A short length of tubing connects the tank to a hand pump (usually single acting). This pump is tubular in shape and is actuated by moving an inner sliding tube backwards and forwards, hand grips being provided on the two parts. A dual nozzle is provided to give a jet or spray.

In some models the tank is so constructed that it will not leak if laid horizontally. This is of importance if the operator must crawl in thick smoke when wearing the knapsack tank.

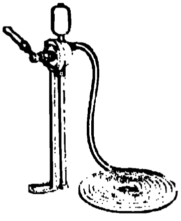


Fig. 5. View of semi-rotary type stirrup pump.

(*b*) *Operation.* The tank is first filled with water from any convenient supply and then slipped on to the back by means of the shoulder straps. The pump is operated as required by means of the grip near the nozzle which is worked backwards and forwards.

(*c*) *Maintenance and Testing.* As for other types of hand pump, care being taken to clean out and dry the tank after use.

(*d*) *Use.* This type of pump is sometimes found in this country, but is very popular in the U.S.A. Advantages are :—

(i) It can be used by one man only.

(ii) The supply of water is carried with the pump.

The disadvantages are :—

(i) When the contents of the tank are exhausted, the operator must stop and go back to the water supply to replenish unless the tank can be refilled on his back by a second man.

(ii) Considerable exertion by the operator is necessary and a steadily directed jet is difficult to obtain.

(iii) The operator must work within close reach of the fire and is subjected to the full effects of heat and smoke whilst indulging in strenuous exertion.

(iv) In some types the tank must be kept reasonably upright to prevent the contents spilling, making it impossible for the operator to crawl with the tank on his back.

(v) The pump cannot be operated in the prone position and full advantage cannot be taken of available cover when dealing with incendiary bombs.

SEMI-ROTARY PUMP

(*a*) *Construction.* The semi-rotary pump is not used extensively in firefighting but is more generally used for pumping liquids from one container into another. A few pumps of this type (Fig. 5) have, however, been produced as stirrup pumps for firefighting. It is a self-priming pump and owing to its design characteristics it is particularly useful for pumping liquids where large quantities under low heads are involved. Typical examples of such use are, as bilge pumps on fireboats or for extracting petrol from an underground tank.

These pumps are sturdily constructed, having a cast-iron body with metal (usually brass or bronze) clack valves, and are operated by moving a handle attached to the central spindle backwards and forwards.

In the double-acting type (Fig. 6) the only moving parts are four clack valves and the wings which are attached to the central spindle. In effect these wings act like a piston, their outer edges being ground so as to make a watertight connection with the inner wall of the pump casing.

The inlet at the base of the pump is screwed to take standard sizes of galvanised water tubing and particular attention should be paid to see that an airtight connection is made when installing the pump.

(*b*) *Operation.* When the wing (Fig. 6, *left*) containing the clack valve (*a*) rises, this valve is closed while the inlet clack valve (*b*) opens and water enters the pump casing (*c*). On the return stroke (Fig. 6, *right*) valve (*a*) opens, valve (*b*) closes and the water passes into the outlet chamber (*d*). At the same time the wing containing valve (*e*) rises, the other inlet valve (*f*) opens and water enters the pump casing (*g*). On each subsequent stroke the water in either (*c*) or (*g*) is expelled into the outlet chamber (*d*) and thence through the discharge pipe (*h*).

(*c*) *Maintenance and Testing.* If the pump fails to operate it is usually due to one of two causes.

(i) A leak in the joint between the suction tubing and the pump. This should be tested before examining the interior of the pump.

(ii) The clack valves failing to close owing to dirt or corrosion.

To dismantle the pump it is necessary to unscrew the hexagonal nuts holding the face plate in position and withdraw the assembly from the pump casing. All valves should then be examined to see that they bed properly and all moving parts greased. When replacing, care should be taken to tighten the nuts so that there is no air leak between the face plate and the pump casing.

(*d*) *Use.* As previously explained, these pumps are principally fitted to small boats for pumping out bilge water or for pumping petrol from underground tanks.

GENERAL

Hand pumps, a term which will, for this section, include stirrup pumps, form a valuable part of first-aid firefighting equipment. Their principal advantages are :—

(i) They are light in weight, easily portable, and the person attacking the fire has only a light nozzle to handle.

(ii) Provided a supply of water is available they can be got to work with considerable speed.

(iii) The jet can be maintained for as long as desired (unlike the chemical extinguisher) and can be turned on or off at will.

(iv) Plain water is used as an extinguishing medium and consequently

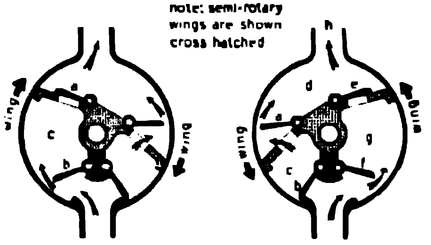


Fig. 6. Section through double-acting type semi-rotary pump. Left : wings rotating clockwise. Right : wings rotating anti-clockwise.

damage to goods is less than when using liquids charged with chemicals.

(v) The initial cost is low, they are simple in construction and operation, and provided they are inspected and tested regularly are very free from breakdown.

(vi) The person pumping is clear of heat and smoke.

The disadvantages are :—

(i) Two and preferably three people are required to operate them, although one person can use the stirrup type pump if adequate water supplies are available within striking distance of the fire.

(ii) A supply of water in buckets must be available or arrangements must be made to carry a portable supply.

(iii) The physical exertion involved in pumping for any length of time is considerable.

In use these pumps are generally operated by a crew of three (see National Fire Service Drill Book), one man taking the nozzle and attacking the fire whilst the other two remain with the pump, one pumping and the other feeding the pump with water. These two change over duties as the man on the pump becomes fatigued.

Hand pumps are of particular value in dealing with small fires of all types for which water is suitable, especially in their incipient stages. Several pumps have also been used simultaneously under air raid conditions for holding larger fires in check until the arrival of the Fire Service. They are of particular value in the case of chimney fires. When used for this purpose after access has been gained to the chimney proper, the nozzle is lashed by means of the belt line, etc., to a broomstick or other suitable long pole and pushed up the chimney. In some localities special chimney rods, described in the Chapter on " Small Gear," are carried for this purpose.

The standard method of extinguishing chimney fires is outlined in the Chapter on " Practical Firefighting."

Prior to the war most ex-regular appliances were equipped with one hand pump, whilst under the emergency scheme all first line National Fire Service appliances carry two stirrup pumps or their equivalent.

These pumps should, as far as possible, be stored away from frost and out of the direct rays of the sun. The former will freeze up the valves and working parts unless the pump has been most carefully drained, whilst the direct sunlight has a very deleterious effect on the rubber of the hose. When making up stirrup pumps care should be taken to coil the hose neatly, avoiding kinks and sudden bends which might cause the rubber to take a permanent set, to crack or to perish. Rubber hose and canvas hose for hand pumps should be cared for in precisely the same way as ordinary delivery hose.

TWO-MAN MANUAL PUMPS

(a) ***Construction.*** Unlike the hand and stirrup pumps, the manual pumps used in firefighting vary considerably in design.

Several types of proprietary pumps are in use and it is beyond the scope of this chapter to examine the working details of each.

In general, however, all pumps have to satisfy the following requirements :—

(i) They must be portable to the extent that one or two men can carry them to the scene of a fire.

(ii) They should be capable of throwing a jet to a distance of approximately 60 ft. through a ½ in. or 5/16 in. nozzle.

(iii) They should be mounted on substantial bases so that they do not move about when operated.

To render the pump more compact and portable, in most models the two handles can be disconnected from the pump or are in the form of extending rods which are pushed in when the pump is stored. The base of the pump is usually constructed in much the same way (Fig. 7).

Double-acting pumps with a single piston or single-acting pumps with twin pistons are employed, the water inlets and outlets in both cases being controlled by clack valves. Some manufacturers incorporate an air pressure chamber in the outlet to ensure an even flow of water, and, if a pressure gauge is included it is usually fixed to this chamber.

Access to the plungers and clack valves is obtained by unscrewing the removable face plates forming part of the cylinders.

The standard equipment includes one length of 1½ in. armoured suction having 1½ in. " V " thread couplings with metal strainer and female coupling. A 2½ in. female instantaneous coupling on the delivery connects to 75 ft. lengths of 1¾ in. canvas or duck-covered rubber delivery hose. The branch is fitted with either a ½ in. or 5/16 in. nozzle.

(b) Operation. The pump is carried to the nearest available water supply. This should be of at least 100 gallons capacity, and arrangements must be made to replenish it as and when water is used. Canvas dams with self-supporting walls are also issued for use with these pumps, the dam being fed by buckets as required. When the pump is in position the pumping handles and base are extended and the delivery and suction hose connected. Care must be taken to ensure that there is no air leak at the inlet to the pump and that the strainer is well below the surface, or it will fail to lift water.

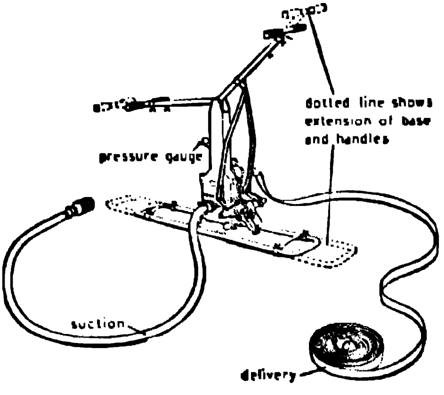


Fig. 7. View of two-man manual.

These pumps are of the self-priming type and after a few strokes with the handles, water should be observed passing through the

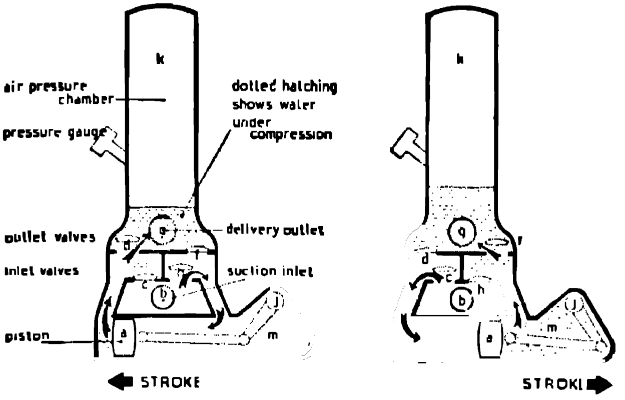


Fig. 8. Left: section through two-man manual, first stroke. Right: section through two-man manual, second stroke.

delivery hose. Pumping should continue at approximately 60 strokes per minute.

When operating at this speed with a vertical suction lift of 10 ft. the pump is capable of providing through 75 ft. of 1¾ in. unlined canvas delivery hose and a ¼ in. nozzle a fire stream at 40 lbs. per sq. in. pressure. Through two 75-ft. lengths of 1¾ in. unlined canvas delivery hose, two ¼ in. fire streams can be provided at a pressure of 30 lb. per sq. in. The use of long lines of delivery hose with this type of pump is not advisable, as a considerable quantity of water is required to charge the hose, and frictional resistance increases proportionately.

The internal working of the pump is shown in Fig. 8.

On the first stroke (Fig. 8, *left*) as the piston (*a*) moves away from the crank-chamber (*m*) the inlet valve (*h*) opens and water is drawn in through the suction inlet (*b*), the outlet valve (*f*) remaining closed. At the same time water is forced by the piston through the outlet valve (*d*) to the delivery (*g*), the inlet valve (*c*) remaining closed.

On the second stroke (Fig. 8, *right*) the action of the various parts is reversed, water being drawn in through the inlet valve (*c*) and discharged through the outlet valve (*f*). The crank-chamber (*m*) remains charged with water throughout both operations, the crank-shaft (*j*) being fitted with a stuffing box gland to prevent leakage.

The function of the air-pressure chamber (*k*) is to maintain an even flow of water from the delivery, thus giving a steady jet. The water entering through the outlet valves rises in the chamber and compresses the air which, in attempting to expand to its original volume, drives the water out through the delivery in a steady stream which is unaffected by the pulsation caused by the reciprocating movement of the piston.

The following equipment is generally supplied with each two-man manual:—

1 10-ft. length of suction hose.
1 copper suction strainer.
2 75-ft. lengths of 1¾-in. unlined canvas hose with 2½-in. instantaneous couplings.
2 branches with ¼-in. nozzles.
1 dividing breeching.
1 canvas dam.
20 canvas buckets.

(*c*) *Maintenance and Testing.* Two-man manual pumps should be tested at intervals of about one month. All working parts should be thoroughly greased and suction and delivery hose examined for any holes.

Failure to obtain water is due to either :—

(i) Faulty suction hose ;
(ii) Choked strainer ;
(iii) Loose connection at suction inlet ;
(iv) Clack valves not operating.

If the suction hose is in order and the strainer clean, the clack valves should be examined by removing the face plates and clearing away any dirt which might be preventing the valves from opening or closing properly. To prevent rusting, the valves and pistons should be coated with grease each time the face plates are removed. Both suction and delivery hose should be maintained as laid down in Chapter 4.

(*d*) *Use.* These pumps are used for fighting fires which are too large for hand pumps and yet do not require a power-driven pump. Factory, institution, street and rural fire parties use them extensively.

Although the term two-man manual is used to denote this type of pump, a crew of five is required, allocated as follows : one man on the branch, two pumping and two to act as reliefs and water carriers. The drill for this type of pump is given in the National Fire Service Drill Book (Drill M.3). Crews should be given regular practice, and it must be remembered that with this as with all other types of pump, fires are extinguished most quickly when the jet is directed into the seat of the fire from as short a distance and with as much force as possible.

PART I CHAPTER 9

PORTABLE CHEMICAL FIRE EXTINGUISHERS

PORTABLE chemical extinguishers are essentially first-aid fire-fighting appliances for use only on fires of certain types when caught in their incipient stages. They are generally sufficiently small and light in weight to be carried readily by hand, and are then known as hand extinguishers. Larger models of certain types, known as chemical engines, may be mounted on a simple two-wheeled chassis which is moved by hand to the fire. In the latter case a length of hose is usually employed to extend the available range of the appliance. The principles of working and the advantages and disadvantages of the chemical engine are precisely the same as for the corresponding type of hand extinguisher.

HAND CHEMICAL EXTINGUISHERS

There are a number of different types of extinguishers in common use; these may be listed as:—

1. Extinguishers which expel water or dilute chemical solutions.
2. Foam extinguishers.
3. Extinguishers which expel vapour-forming liquids, or gases.
4. Dry powder extinguishers.
5. Emulsions.

I. EXTINGUISHERS WHICH EXPEL WATER OR DILUTE CHEMICAL SOLUTIONS

(*a*) *Soda-acid.* Far the most common and the oldest form of chemical extinguisher is the soda-acid type, which is widely installed by householders and in factories, business premises and other public buildings. This extinguisher consists essentially of a cylindrical or conical container which is normally filled to somewhere in the neighbourhood of two-thirds of its capacity with water. This water is ejected on to the fire by the pressure of a gas generated by a chemical action set up by allowing a charge of acid to react with a carbonate or bicarbonate which has previously been dissolved in the water. The gas thus generated exerts a downward force on the surface of the liquid and drives it out of the extinguisher through a nozzle which is directed by the operator at the fire. Sodium bicarbonate and sulphuric acid are the two chemicals normally used for generating the gaseous carbon dioxide, which is almost universally used as the expelling medium. The reaction takes place according to the equation:—

$$2NaHCO_3 + H_2SO_4 = Na_2SO_4 + 2H_2O + 2CO_2$$

(Sodium bicarbonate) + (Sulphuric acid) = (Sodium sulphate) + (Water) + (Carbon dioxide)

In practice a considerable excess of sodium bicarbonate is used, to obviate the possibility of any free acid being discharged and damaging the material on which the liquid falls. Where, for a particular risk, sulphate-impregnated water is not desirable, an organic acid may be substituted, but owing to this type of acid being less reactive, larger volumes are required and modifications to the acid-containing arrangements in the extinguisher may be necessary.

It should be emphasised that although carbon dioxide is produced in considerable volume by the operation of this extinguisher it is the water which forms the extinguishing medium. Relatively the nozzle is so small, the quantity of CO_2 so slight, and the distance from the fire at which the extinguisher is operated so great, that except in rare instances, the carbon dioxide plays no part in the extinction of the fire.

The British Standards Institution have framed a specification (No. 138) detailing certain minimum requirements in this type of extinguisher, and all the better known manufacturing firms adhere to this specification, although there is no legal obligation to do so. The Fire Offices' Committee tests and approves extinguishers of this and other types. Certification that an extinguisher complies with either of these requirements assures the purchaser of a certain minimum performance. A brief summary of the British Standards Institution Specification is as follows :—

The form of nozzle, and the area of the orifice must be such that the contents are projected to a distance of not less than 20 ft. for the minimum period, and discharge must be completed in the maximum period shown below :—

Capacity	Minimum Period	Maximum Period
1 gallon	40 secs.	80 secs.
2 gallons	60 secs.	120 secs.
3 gallons	70 secs.	140 secs.

The required liquid level must be permanently indicated, and the air volume above the liquid level must be not less than 5 per cent. of the total volume. When the extinguisher is actuated at 100° F. and the outlet temporarily closed, the pressure must not rise higher than 200 lbs. per sq. in.

The charge shall consist of :—

(*a*) carbonate and/or bicarbonate in solution of such strength that no precipitation of solids shall take place at 60° F., and

(*b*) an acid (in a bottle) in such proportions that when brought together the resulting solution is alkaline.

Extinguishers must, when new, be capable of withstanding an internal pressure test of 350 lbs. per sq. in. for 5 minutes without leakage or visible distortion and must have been tested by the manufacturer at this pressure for at least 2½ minutes.

Every extinguisher must be clearly labelled in a permanent manner with certain details as to the name of the maker, capacity, year of manufacture, etc.

The discharge tube (or the nozzle in turn-over types) must also be so arranged that not less than 95 per cent. of the contents are discharged.

In normal use the maximum pressure generated will not exceed 100 lbs. per sq. in., when charges prepared by the makers are employed. If the charges are made up from the individual chemicals by members of the Service, it is essential to ensure that only the correct proportions are used. Any increase in the acid charge will cause a pressure rise.

There are a number of different types of soda-acid extinguisher. The difference between each type depends on the means employed to bring the acid and the main charge into contact, and they may be divided into two groups :—

(i) Those which are operated in their normal upright or nearly upright position, and

(ii) those which are inverted to initiate the action and which are operated in this position.

(i) *Soda-acid Extinguishers operated in an Upright Position*

A. CONICAL TYPE WITH PLUNGER ON TOP. One of the most common types (Fig. 1, *left*) is conical in shape with a nozzle (*a*) near the top. Inside the body is a discharge tube (*b*) which runs almost to the bottom and is fitted at its lower end with a strainer (*c*) to prevent small particles of glass or of precipitated bicarbonate clogging up the discharge tube or nozzle. At the top is a brass casting with a knob or plunger (*d*) in the centre. On unscrewing the casting a cage (*e*) will be found holding a glass phial (*f*) containing

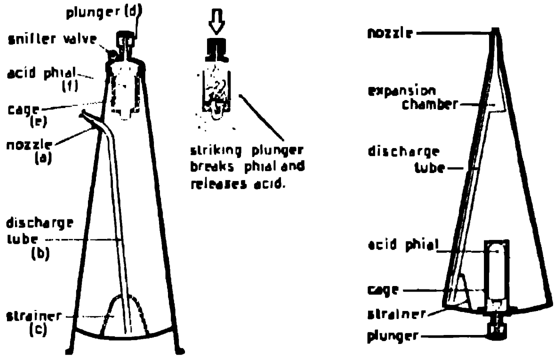


Fig. 1. Sections through conical type soda-acid extinguishers : Left : with plunger at apex. Right : with plunger at base.

the sulphuric acid charge. The body of the extinguisher contains the water with bicarbonate in solution. Striking the plunger breaks the phial and allows the acid to escape and thus set up the necessary chemical reaction.

B. Conical Type with Plunger at Base. Almost equally common is the conical type (Fig. 1, *right*) which has a plunger at the bottom instead of the top, which is struck either on the ground or by hand to actuate the extinguisher.

C. Cylindrical Type with Plunger on Top. In this type (Fig. 2, *left*) the body is cylindrical but otherwise the general arrangement is similar to that of type A.

D. Cylindrical Type with Hammer at Side. In this type (Fig. 2, *right*) the body (*a*) is cylindrical, but the phial (*b*) is broken by a hammer (*c*) located on the side of the container and secured in position by a split pin (*d*) to prevent accidental movement of the hammer. The phial is of a special shape and rests in a breaking ring (*e*). The hammer is so located that its impact on the side of the extinguisher sets up sufficient vibration in the breaking ring to fracture the glass phial, thus releasing the acid.

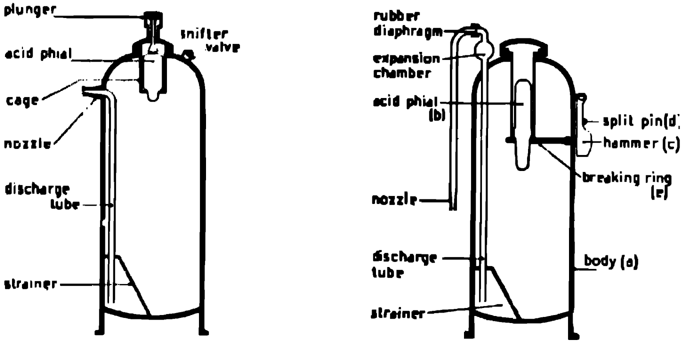
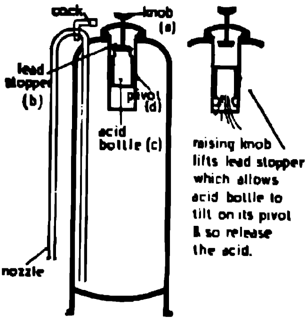


Fig. 2. Sections through cylindrical type soda-acid extinguishers. Left : with plunger at top. Right : with hammer at side.

E. Tilting Bottle Type. In a further cylindrical type (Fig. 3) the knob (*a*), to which a lead stopper (*b*) is attached, is raised to actuate the extinguisher. This allows the acid bottle (*c*) which is eccentrically pivoted (*d*) to overturn and release the acid into the bicarbonate solution.

Nozzles and Discharge Cocks. In types A and B, and sometimes in C, the nozzle usually forms part of the main body of the extinguisher, whilst in types D and E a short length of flexible tubing is usually employed with a nozzle at the end. In older models of these latter types, a cock may be fitted just above the point where the discharge tube leaves the body. The use of this cock has been discontinued under British Standard Specification No. 138 as it may easily seize unless given regular and skilled inspection. If it seizes in the closed position dangerous internal pressures may easily be built up if the extinguisher is old and in poor condition. The original intention of this cock was to prevent overflow and to shut off the jet to prevent excessive water damage, etc. A number of extinguishers carried on Fire Service appliances are still fitted with such a cock since the same objections do not apply where equipment is subjected to frequent and careful inspection and testing.



raising knob lifts lead stopper which allows acid bottle to tilt on its pivot & so release the acid.

Fig. 3. Section through tilting bottle type soda-acid extinguisher.

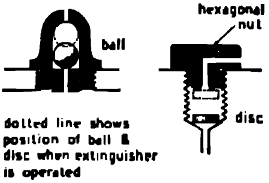
PRECAUTIONS AGAINST LOSSES DUE TO EXPANSION. When an extinguisher, fitted with a discharge tube, is left standing fully charged, an increase in the temperature of the room causes the fluid and the air to expand inside the container. Under ordinary circumstances, the expansion would force some of the fluid up through the discharge tube and out through the nozzle. The solution then collects in a small globule at the end of the nozzle. The water evaporates and leaves bicarbonate of soda in solid form in the orifice of the nozzle. If this process continued, the nozzle would eventually become solidly blocked and would render the extinguisher ineffective.

To prevent this, one or other, or even in some cases all, of three safeguards have been provided in certain of these types.

1. At the point where the discharge tube leaves the cylinder or internally above the liquid level, an expansion chamber forming part of the discharge tube is provided. This is clearly shown in Fig. 1, *right*, and in Fig. 2, *right*. This gives additional space to be occupied by the fluid on expansion.

2. Within the union which connects the rubber hose to the extinguisher (Fig. 2, *right*) a diaphragm of thin rubber mounted on a washer is inserted. This rubber diaphragm is capable of withstanding the slight increase in pressure caused by expansion, but is easily ruptured by the pressure generated when the extinguisher is brought into operation.

3. Other types employ what is known as a snifter valve. This is a valve (Fig. 1, *left*, and Fig. 2, *left*) which communicates from the atmosphere with the air space in the extinguisher and permits the very small quantity of air to escape when the internal pressure rises slightly. A ball or a rubber composition disc (Fig. 4), which may be grooved, rests lightly on an orifice connecting with the body of the extinguisher and allows the air to seep past and away to atmosphere.



dotted line shows position of ball & disc when extinguisher is operated

Fig. 4. Left : section through ball-type snifter valve. Right : section through disc-type snifter valve.

When the extinguisher is operated, the high internal pressure lifts the ball or disc firmly against a seating which completely seals the outlet.

(ii) *Turn-over Types of Soda-acid Extinguisher.* The three remaining types of extinguisher operate on a different principle. They are inverted to initiate the action and operated in this position.

A. OPEN BOTTLE TYPE WITH LEAD STOPPER. In this type (Fig. 5, *left*) there is no striking mechanism. The body (*a*) is cylindrical and the acid is contained in an open vessel (*b*) with a lead stopper (*c*) on top. (Lead is resistant to attack by sulphuric acid.) When the extinguisher is turned upside down the lead weight falls away and the acid mixes with the bicarbonate solution. The gas rises to what was the bottom (now at the top) and forces the liquid out through the nozzle, which is now at the bottom.

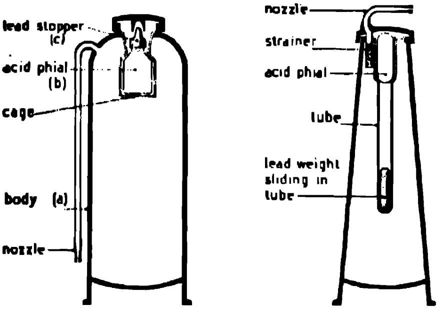


Fig. 5. Sections through turn-over type soda-acid extinguishers. Left : with lead stopper. Right : with sliding lead weight.

B. SEALED BOTTLE TYPE WITH SLIDING LEAD WEIGHT. This is a conical type (Fig. 5, *right*) in which a sealed bottle or phial of acid is shattered by a lead weight which slides along an inner tube when the extinguisher is inverted. As in other "break-bottle" types a strainer is fitted to prevent fragments blocking the nozzle.

C. TURN-OVER TYPE WITH PLUNGER. This type differs from the other turn-over types in that it is operated by first turning upside down and then driving in a plunger which shatters a glass phial.

It should be noted that the turn-over types do not require a snifter valve as they are not fitted with a discharge tube. Any pressure which might be built up through temperature changes escapes immediately to atmosphere through the nozzle.

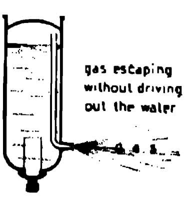


Fig. 6. Diagram showing how gas escapes without driving out the contents when an extinguisher is reversed from its operating position.

The importance of correctly identifying the method of working these extinguishers needs no emphasis. If a type operated in the upright position is inadvertently used in the turn-over position the gas pressure will escape through the discharge tube leaving the liquid contents behind (Fig. 6), whilst if a turn-over type is brought into operation and then returned to its normal upright position the CO_2 will be ejected through the nozzle and the liquid, having no pressure behind it to drive it out, will remain in the extinguisher.

When it is certain that a fire has been extinguished and it is desired to obviate any further water damage by the continued discharge of the extinguisher, the latter may be reversed from its operating position, when the gas will escape without driving out the contents. It must be appreciated that once the gas has been discharged in this way, however much of the contents remain undischarged, the extinguisher is useless for further firefighting until it is recharged.

Recharging. Soda-acid extinguishers should be recharged as soon as possible after use. Whilst the different types vary considerably, recharging should be carried out as far as possible in the following order :—

(i) Unscrew and remove the head. In carrying out this operation, keep the head of the extinguisher away from the operator. It is possible the container may still be under pressure and if the head is detached under these conditions it is likely to be blown off the extinguisher with some force and may cause injury to the operator.

Most fire extinguishers having removable heads have a safety device in the form of several holes drilled in the side of the head through the screw thread. As the cap is unscrewed these holes communicate with the interior of the container and any residual gas pressure discharges through them whilst the head is still held in position by the threads. These holes are not infrequently choked either with dirt or metal polish and care should be taken at the regular inspection to ensure that they are cleaned and capable of fulfilling their function.

(ii) Withdraw the cage or other bottle holder if this is detachable.

(iii) Thoroughly wash out the container, removing any pieces of solid matter, broken glass, etc., which may be found in it.

(iv) Measure out the chemicals required, or, where ready made-up charges are employed, open the tin containing the recharging chemicals. Great care should be taken in handling the sulphuric acid phial or bottle. In those fitted with a seal at the top this is very thin, and the slightest abrasion will break the seal and allow the acid to escape, rendering the charge useless.

(v) Thoroughly mix the bicarbonate of soda with a quantity of warm water in a clean bucket. The water must not be *hot* as this tends to break down the bicarbonate. Pour this solution into the body of the extinguisher and fill up to the correct level with cold water. On no account should the extinguisher be over-filled as this reduces the expansion space above the liquid and may set up dangerous pressure when it is actuated.

(vi) If a rubber seal is fitted at the top of the discharge tube, disconnect the rubber hose at the union and remove the old rubber diaphragm. Blow down the discharge tube ; this causes bubbles to pass through the solution in the cylinder and gives assurance that the discharge tube is not obstructed. Blow down the rubber hose to ensure that this is clear. Insert new rubber diaphragm in union and attach the rubber hose to the extinguisher. The nozzle, hose and discharge tube should always be carefully examined to see that they are perfectly free from obstruction.

(vii) If a plunger is used see that it works freely. Grease very lightly.

(viii) Insert the bottle of sulphuric acid in the carrier, making sure that it is the right way up, then place in the extinguisher.

(ix) Slightly grease the threads on the top of the container, but be careful that grease does not reach the gasket which makes the gastight joint. This may otherwise rot in course of time and blow out when the extinguisher is put to work. Then screw head down tightly.

(x) If a hammer is employed, secure it by the pin.

(xi) Under no circumstances make any variation in the proportions of the charge.

Testing. All extinguishers of this type are to be opened up for inspection quarterly, and tested by discharge annually, from the date on which they were last tested or were used at a fire.

All extinguishers are lead-coated internally to resist corrosion, but, despite this, electrolytic action may at times take place. Regular pressure testing is therefore essential to detect incipient weakness and every two years each extinguisher should be subjected to a pressure test of 350 lbs. per sq. in.

Frost Danger. On no account should extinguishers containing water and bicarbonate be exposed to temperatures lower than 40° F., as the bicarbonate in solution will tend to precipitate at from 36° to 38° F. Lower temperatures also, may produce a noticeable retardation of action even though precipitation is not evident. The best temperature for operation is around 60° F. The addition of non-freezing compounds, such as calcium chloride or common salt, to the contents should in no circumstances be allowed. Extinguishers have frequently been rendered inoperative and fatalities have occurred as the result of extinguishers, which have corroded due to such treatment, bursting when brought into operation.

Use. Soda-acid extinguishers (of all types) should not be used on any fire where there is risk of the jet coming into contact with live electric wiring. The jet is a conductor, due in large measure to the chemical contents of the water. Neither should they be used for fires involving burning oils, spirits or highly inflammable liquids, as the jet will splash and spread the fire and the burning liquid will float on top of the extinguishing medium.

When using a soda-acid extinguisher wait until you are as near to the fire as possible before actuating it. Direct the jet on to the burning material in the heart of the fire, disregarding the flames and the smoke.

Advantages and Disadvantages.

The advantages of the soda-acid type extinguisher are :—

(i) For first attack on a fire it is often the most readily accessible fire-fighting appliance.

(ii) Only one person is needed to work it.

(iii) When kept in good working order it is reliable.

(iv) It is self-contained, having a capacity sufficient to deal with minor outbreaks.

(v) It is almost instantaneous in action.

(vi) It has only one moving part.

(vii) The length of the stream may be expected to reach 30 to 40 ft., but there is every advantage in using the stream at a shorter distance, where possible.

The disadvantages are :—

(i) From point of view of the Fire Service, once the action is initiated the extinguisher must be completely discharged before being refilled.

(ii) As the liquid discharged is a conductor of electricity, it should not be directed on to live electrical apparatus.

(iii) As with any appliance using water, it requires protection against freezing; at low temperatures the chemical reaction may develop slowly.

(iv) The liquid ejected contains a chemical (sodium sulphate). Clothing and fabrics may in some cases be affected by the liquid.

(v) Certain types of fire, *e.g.*, those below floorboards, etc., cannot be tackled successfully with an extinguisher which will not operate in the inverted position unless fitted with a sufficient length of hose.

(b) Compressed Gas Cartridge Type Extinguisher. Certain of the drawbacks inherent in the soda-acid extinguisher have been overcome by employing an outer container (Fig. 7) of very similar construction, holding approximately 2 gallons of water, but in lieu of generating the gas used to expel the contents by chemical action, it is released from an inner container (*a*) in which it is stored inside the body of the extinguisher in a highly compressed state. There is some variation in the pressure at which gas is stored in the cartridge or inner container but the pressures employed are normally in the region of several hundred lbs. per sq. in. The general construction of the outer container is very similar to that of the soda-acid extinguisher, it has an expansion space at the surface of the liquid and a discharge tube (*b*). The cartridge (*a*) is normally made of copper (to resist corrosion) tested to high pressure with a small sealing disc (*c*) at the top which is pierced when the extinguisher is actuated, by means of a pointed striker (*d*), at the lower end of the plunger (*e*). The appearance of the extinguisher is very similar to that of the ordinary soda-acid type. The knob is protected from accidental operation by a loosely fitting cap which is removed to strike the knob.

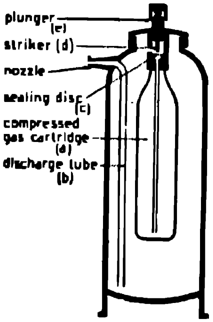


Fig. 7. Section through compressed gas cartridge type extinguisher.

The cartridge may contain CO_2, nitrogen, or other suitable inert gas. When the disc is pierced, the gas contained in the capsule is released into the body of the extinguisher, driving the liquid contents out through the discharge tube. The principal advantages claimed for this type are :—

(i) The expelled fluid may consist of pure water only, thus avoiding possible damage such as is caused by the chemically charged water discharged by a soda-acid extinguisher.

(ii) Other liquids may, however, be used to deal with special types of risk.

(iii) Certain models can be rapidly recharged. The cap is fitted with a hand-wheel which enables it to be rapidly unscrewed. The old cartridge can be removed, the container refilled and a fresh cartridge of gas dropped into place. Immediately the cap is screwed down the extinguisher can be put to work again. For some makes it is claimed that this operation can be carried out in 30 seconds. If the first charge has failed, however, it is probable that the fire is beyond the capacity of 2 gallons of water and even 30 seconds delay is serious; the second charge will probably be less effective.

(iv) Providing a non-corrosive chemical is employed there should be no objection to the employment of charges which would prevent freezing in cold weather.

(v) As the gas is released mechanically, low temperatures do not retard the action as in the case of the soda-acid extinguisher, which is very slow when the temperature falls to 40° F.

(vi) In certain makes of this type of extinguisher the cartridge may, with simple apparatus, be filled by the owner and a new disc sealed into position.

The disadvantages of this type are :—

(i) It is impossible to be certain that the capsule is fully charged and free from leaks.

(ii) It cannot normally be exposed in positions liable to freezing unless a special charge is employed.

As this extinguisher is not widely used by the Fire Service no standard test is specified.

Another type of compressed gas cartridge extinguisher in which the gas is contained in a capsule in liquid state under high pressure is also in use. It is proposed to deal with this appliance more fully in any revision of this part of the *Manual*.

2. FOAM EXTINGUISHERS

The hand type foam extinguisher normally has a capacity of not less than one, or more than two gallons.

British Standard Specification No. 740 details the materials and the thicknesses which are to be used for construction. The form and size of the nozzle must be such that when actuated the extinguisher is capable of throwing a jet of not less than 20 ft. for the minimum time and the whole of the expellable foam shall be ejected within the maximum times shown below :—

Capacity	Minimum Period	Maximum Period
1 gallon	20 secs.	60 secs.
2 gallons	30 secs.	90 secs.

The foam is produced by the reaction of two chemical solutions which are stored in concentric compartments within the container. This reaction takes place according to the following formula :—

$$\underset{\text{(Aluminium sulphate)}}{Al_2(SO_4)_3} + \underset{\text{(Sodium bicarbonate)}}{6NaHCO_3} = \underset{\text{(Aluminium hydroxide)}}{2Al(OH)_3} + \underset{\text{(Sodium sulphate)}}{3Na_2SO_4} + \underset{\text{(Carbon dioxide)}}{6CO_2}.$$

The level of the solution in the outer compartment must be permanently indicated outside and there must be an air space in the outer compartment above the required liquid of not less than 5 per cent. of the total volume. As in the soda-acid extinguisher, the outer compartment is of sheet metal, either cylindrical or conical, lead coated inside to prevent corrosion, and is tested to 350 lbs. per sq. in. for at least 2½ minutes without visible distortion or leakage. The inner compartment holds a liquid which when mixed with the contents of the outer compartment sets up the chemical action which produces foam and discharges it through the nozzle.

The solution in the inner compartment is generally aluminium sulphate (approximately 13 per cent.) dissolved in water, whilst the other solution is about 8 per cent. bicarbonate of soda together with about 3 per cent. of a stabiliser such as saponine, liquorice or turkey-red oil, also dissolved in water. When made up charges for these extinguishers are supplied, the exact composition is retained as a trade secret by the manufacturer, each of whom has his own formula. A detailed description of foam, its constitution and formation, will be found in Chapter 10.

Foam extinguishers are invariably actuated by turning upside down, and are operated in that position. Foam extinguishers fall into three main groups :—

(*a*) Those in which the action is initiated by simply inverting the extinguisher.

(*b*) Those in which an additional seal is provided which must be unlocked before the extinguisher is inverted to operate.

(*c*) Those in which a break-bottle or break-seal mechanism is included, which must first be operated.

(a) Turn-over Type. In the simplest turn-over type (Fig. 8, *right*) the inner compartment (*a*) has at the top a series of port-holes (*b*) ; when the extinguisher is inverted the two solutions mix, the chemical action is initiated and foam is discharged through the nozzle (*c*).

(b) Bayonet Seal Type. When foam extinguishers are to be carried upon vehicles the vibration of which would cause the contents of the inner compartment to spill, or when it is necessary to reduce to a minimum the possibility of evaporation of the contents, a sealing arrangement is employed (Fig. 8, *left*). This, in most instances, embodies two valves, one of which (*a*) seats upon a shoulder on the inner compartment just below the portholes (*b*) and closes it, whilst the other (*c*) seals the small outlet space in the cap. In this way the accidental mixing of the solutions is prevented and the passage to the nozzle closed. The sealed type of extinguisher is brought into operation either by operating a lever or by a half-turn

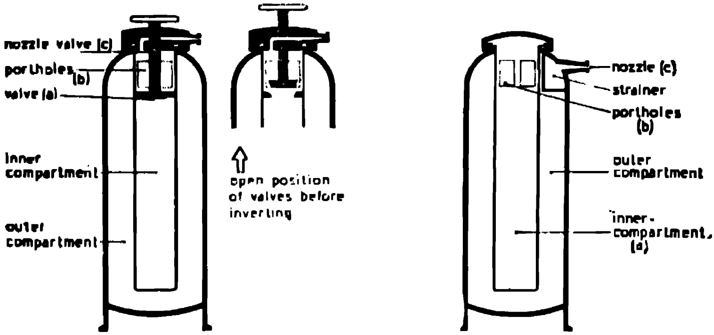


Fig. 8. Sections through foam extinguishers. Left : bayonet seal turn-over type. Right : turn-over type without seal.

of a handle, before inverting. In some models the discharge nozzle forms part of the compartment whilst in others the " T "-shaped handle has one hollow arm terminating in a nozzle.

(c) *Plunger Type*. In this type the inner compartment is sealed by means of a mica disc and strike knob mechanism is provided in the head. To actuate, the knob is struck, thus puncturing the disc, and the extinguisher is inverted. The nozzle forms part of the body and is not sealed, thus allowing the extinguisher to " breathe " with variations in temperature.

Recharging. Foam extinguishers which have been discharged should be recharged as soon as possible and this should be carried out in the following manner :—

(i) Remove the head by unscrewing.

(ii) Extract the inner compartment.

(iii) Thoroughly wash all parts, removing any solid matter which may be found.

(iv) Thoroughly dissolve the powders supplied in *separate* clean buckets, and according to the directions on the tins.

(v) Pour the main volume of liquid into the outer compartment.

(vi) Pour the aluminium sulphate solution into the inner compartment while it is still removed from the extinguisher. Any of the liquid which has been spilled on the outside of this compartment should be wiped off, and the compartment should not be filled to the brim.

(vii) Carefully insert the inner compartment into the extinguisher.

(viii) If a sealed type is employed, withdraw the plunger to the open position.

(ix) Blow through the nozzle to make sure that this is not obstructed.

(x) Slightly grease the threads (the same remarks apply on this subject as were made for the soda-acid type) and screw cap down tightly.

(xi) Secure plunger (if fitted) in closed position.

Testing. Foam extinguishers are to be opened up and the liquids stirred once a month. Care must be taken not to use the same stick for stirring both solutions. A wooden stick should always be used in order to prevent damage to the lead coating of the extinguisher. Solutions should not be poured into separate containers for stirring, as this leads to wastage and there is a tendency to top up with water and thus alter the strengths of the solutions.

Extinguishers in the National Fire Service at the time of publication of the *Manual* are to be tested by discharge annually, the period dating from the last discharge, whether at a fire or for purposes of test. They must be subjected to a pressure test of 300 lbs. per sq. in. every two years.

Use. Foam extinguishers are used principally to attack fires in burning liquids, etc., which they extinguish by the blanketing action of the foam layer.

When the burning liquid is contained in a tank the jet must not be allowed to strike the liquid but must be directed on to the side of the tank so that it flows down into the burning liquid without stirring it up. If the burning liquid is flowing freely on the ground the jet should not be allowed to strike obliquely as this would stir the surface liquid into motion and expose more liquid to the air. The extinguisher should be kept at such a range that the foam falls vertically on the liquid.

Advantages and Disadvantages. The foam extinguisher has many advantages in common with the soda-acid type, in addition :—

(i) It coats the burning surface of the substance and excludes oxygen.

(ii) It has considerable heat-resisting qualities as an insulator and serves to prevent re-ignition.

(iii) It is not affected by draughts.

(iv) It floats on liquids.

Its principal disadvantages are that :—

(i) Foam mixes with certain liquids and renders them unusable.

(ii) It is not effective on fires in certain types of liquids.

3. EXTINGUISHERS WHICH EXPEL VAPOUR-FORMING LIQUIDS, OR GASES

It has been explained in Chapters 1 and 2 that one of the methods employed in extinguishing fire consists of asphyxiating the flames by diluting the atmosphere with a suitable chemical and thus excluding oxygen in the quantities required to maintain combustion. This exclusion of oxygen may be effected either mechanically or by a blanket of vapour which will not support combustion. It is not necessary to create an atmosphere which consists solely of a gaseous extinguishing medium in order to prevent combustion. There is for each extinguishing medium a certain proportion in air which will procure extinction. This proportion is known as the " inhibitory factor." Thus the inhibitory factor for carbon tetrachloride, for example, is 15 per cent.—that is to say that if a fire can be surrounded with an atmosphere containing 15 per cent. or more of carbon tetrachloride it will be extinguished.

The properties of many substances have been examined to consider their suitability for use in extinguishers. The most satisfactory of these have been found to be (*a*) carbon tetrachloride; (*b*) methyl bromide; and (*c*) carbon dioxide. The physical properties of these substances, and hence their suitability as extinguishing media, can be compared in Table I below (the same properties for water are also given as a standard for comparison):—

TABLE I

	Water	Carbon Tetrachloride	Methyl Bromide	Carbon Dioxide
Chemical formula . . .	H_2O	CCl_4	CH_3Br	CO_2
Molecular weight (0 = 16) . .	18	153·8	94·95	44·0
Specific gravity of liquid . .	1	1·595	1·73	0·835
Vapour density (air = 1 at N.T.P.)	—	5·31	3·27	1·52
Boiling point (degs. F.) at atmospheric pressure . . .	212	170·24	40·28	−109·3
Melting point (degs. F.) . .	+32	−8·68	−135·4	—
Specific heat of liquid at 32 degs. F.	1	0·198	0·12	0·20
Gas generation at N.T.P. (cu. ft. per lb.)	19·7	2·3	3·7	8·0
Latent heat of vaporisation (B.Th.U. per lb. at boiling point)	973	182·4	246	345
Vapour pressure at 60 degs. F. (lbs. per sq. in.)	0·25	1·75	20	760
Normal pressure in container (lbs. per sq. in.)	—	Nil	50	744
Inhibitory factor per cent. in dry air (very approximately) .	—	15·0	3·5	19 to 29

(*a*) *Carbon Tetrachloride Extinguishers.* The most widely used of the chemical type extinguishers is the carbon tetrachloride, commonly known as the C.T.C. extinguisher.

When this liquid is directed on to a fire it vaporises, thus forming a layer of gas which is approximately 5⅓ times as heavy as air. This blanket of vapour consequently displaces the air round the fire and cuts off the oxygen supply needed to maintain combustion. The construction of C.T.C. extinguishers is covered by British Standard Specification No. 740, which, amongst other things, lays down two tables which specify the maximum and minimum time of discharge for the various types. The length of jet which every extinguisher must furnish is 25 ft. Adequate expansion clearance is stipulated in the case of extinguishers of the gas pressure type, and requirements are given as to maximum pressures allowable. All extinguishers of this type in which the working pressure exceeds 50 lbs. per sq. in. must withstand an internal pressure test of 350 lbs. per sq. in. for 5 minutes without distortion and must have been tested by the manufacturers to this pressure for not less than 2½ minutes. The usual requirements as to marking are included.

Much has been spoken and written regarding the dangers of using C.T.C. in an enclosed space. This substance is closely related to chloroform and possesses very similar anæsthetising properties. C.T.C. extinguishers should not, therefore, be used in an enclosed space where the operator must of necessity inhale a high proportion of the fumes generated. Fatalities have resulted through this cause, the susceptibility of various individuals to its poisonous effects varying very greatly. In addition, in the presence of a hot surface, such as that of a metal, where combustion is not actually taking place, the liquid tends to dissociate into chlorine and free carbon which, at the temperatures existing in the fire, will combine with any oxygen present to form carbon monoxide and carbon dioxide. Carbon monoxide may, under suitable conditions, combine with the free chlorine to form phosgene, an extremely poisonous gas, whilst the free chlorine is also poisonous. The reaction probably takes place according to the equation :—

$$CCl_4 = C + 2Cl_2$$
$$2C + O_2 = 2CO$$
$$CO + Cl_2 = COCl_2$$

It is also possible that it breaks down directly into phosgene and hydrochloric acid according to the reaction.

$$CCl_4 + H_2O = COCl_2 + 2HCl.$$

C.T.C. breaks down (or hydrolyses) in the presence of water, yielding hydrochloric acid according to the equation

$$CCl_4 + 2H_2O = CO_2 + 4HCl.$$

It is therefore imperative that it should at all times be kept dry, otherwise the acid released will attack the metal of the container with serious results, especially in the case of pressure types.

As C.T.C. extinguishes fire by the exclusion of oxygen, a hard-striking jet is not essential as in the case of soda-acid extinguishers. Some extinguishers of this type have therefore been fitted with an atomising nozzle through which the C.T.C. is ejected in a finely divided state.

Commercial C.T.C. hand extinguishers fall into the following three main types :—

(i) Pump type.
(ii) Compressed gas-cartridge type.
(iii) Air pressure type.

(i) *Pump Type.* This type is the most widely known since it is sold very largely for use on motor vehicles for dealing with fires in which, C.T.C. is particularly suitable. It consists of an outer container having a liquid capacity usually of 1 quart (but larger models up to 2 gallons are available), inside which is fitted a single- or double-acting force pump. In the smaller sizes the handle actuating the pump is located at one end of the container and the nozzle centrally at the other end. The pumping handle is almost invariably fitted with a bayonet joint and before getting to work the handle is given a partial turn and then operated up and down whilst the resulting jet is directed at the heart of the flames. The pump intake mechanism is constructed so that however the container is held it can swivel internally in order that the intake will always be at the lowest part of the container and thus draw on the bulk of the contents. (A diagrammatic drawing showing the operating principles is given in Fig. 9.) This is essential as the extinguisher may require to be pointed upwards or downwards to deal with a fire.

The plunger consists of a sleeve (*a*) closely fitting in a barrel (*b*). This sleeve is free to slide a short distance between two stops (*c*) and (*d*) which are rigidly connected to the hollow plunger rod (*e*). When the handle is operated the whole assembly moves up or down on the inner discharge tube (*f*).

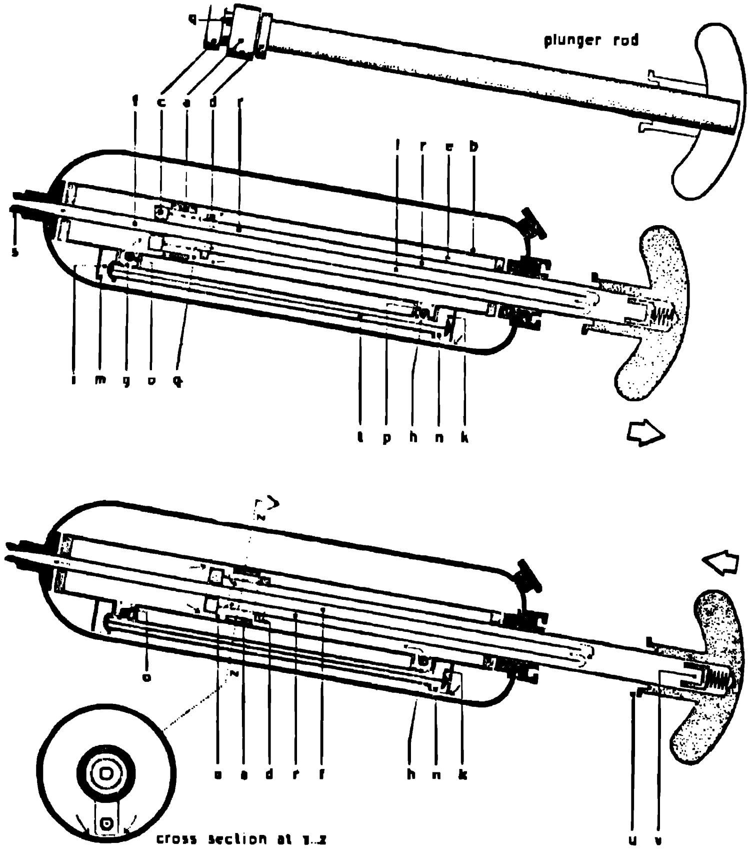


Fig. 9. Section through pump type C.T.C. extinguisher.

The pump has two intakes (*g*) and (*h*), only one of which is in operation at a time. If the pump is tilted down towards the handle as in Fig. 9, *above*, a sliding rod with a mushroom valve at each end, (*j*) and (*k*), slides to the right and seals the inlet (*m*), whilst if the pump is tilted down towards the nozzle the rod slides to the left and the mushroom valve (*k*) shuts off the inlet (*n*). Entry to the pump chamber is governed by the ball valves (*o*) and (*p*).

Thus on the out-stroke when the extinguisher is tilted toward the handle, the pressure of the liquid in the pump barrel (*b*) forces the sleeve (*a*) against the stop (*c*), the liquid in the barrel then passes through the portholes (*q*) into the outer tube (*r*) (formed by the plunger-rod (*e*) and the discharge tube (*f*)), down through the discharge tube and out at the nozzle (*s*). During this stroke the ball valve (*p*) is held on its seat by the pressure of the liquid whilst, below the plunger, the ball valve (*o*) opens and liquid is drawn from the main body of the extinguisher *via* the inlet (*n*) past the mushroom valve (*k*) which is now open, and along the inlet passage (*t*).

In Fig. 9, *below*, is shown the instroke with the extinguisher tilted down towards the handle. The sleeve (*a*) is now forced against the stop (*d*), the liquid in the pump barrel escaping as before up the outer tube (*r*), and then down the discharge tube (*f*) to the nozzle. The ball valve (*o*) is held on its seat by the pressure of the liquid. Meanwhile liquid from the outer container is drawn *via* the inlet (*n*) past the mushroom-headed valve (*k*) which is open and into the pump barrel *via* the intake (*h*).

When the handle is pressed home and the bayonet lock (*u*) secured, a sealing device (*v*) shuts the top of the discharge tube and prevents the escape of the contents.

Minor differences in design will be found in the models produced by various manufacturers. These may consist of ball valves to replace the sliding rod and mushroom valve, variations in the size and disposition of the inlets and in the arrangement of the plunger mechanism. The general operating principles as applicable to the swivelling intake gear, however, remain the same.

The single-acting pump type is somewhat similar in construction but is of simpler design and does not, of course, give a continuous jet. In the larger sizes a rubber hose or rubberised canvas is used to direct the stream on to the fire.

(ii) *Compressed Gas-cartridge Type.* This type of extinguisher is somewhat similar in its general arrangement to the gas-cartridge type of extinguisher using water (Fig. 7). The C.T.C. is contained in the main body whilst a cartridge of highly compressed gas is held in a suitable cage in the container. A plunger is fitted on the top of the extinguisher which when depressed or struck perforates a copper sealing diaphragm on the head of the gas cartridge releasing the gas into the main body of the extinguisher and driving out the liquid contents through a discharge tube. In one particular model the compressed gas capsule can be sealed again by a patent type of knife-edged re-sealing device. It need hardly be remarked that such re-sealing can be of a temporary nature only and that a fresh capsule must be employed when the extinguisher is put back again for future use.

In this type of extinguisher the gas is ejected at the same time as the liquid, breaking the latter up into a highly atomised spray forming a narrow cone. It is claimed that the fine state of division causes instantaneous vaporisation on reaching the fire, with consequent speed in producing a gas blanket.

(iii) *Air Pressure Type.* In this type of extinguisher (Fig. 10) the liquid is held in a container which is fitted with an air pump and a discharge tube. The discharge tube is controlled by a cock which is normally kept in the off or shut position. When it is desired to bring the extinguisher into use the air pump is worked by hand until sufficient air pressure (about 50 lbs. per sq. in.) is built up in the container. A pressure gauge is fitted to register this. The cock is then opened and the stream of liquid directed at the fire.

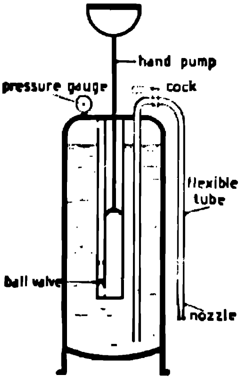


Fig. 10. Section through air pressure type C.T.C. extinguisher, showing air pump, pressure gauge and control cock.

Testing. The pump type C.T.C. extinguishers used by the National Fire Service are to be examined for leakage once a week. At the time of publication of this *Manual* a monthly test is carried out as follows: Pump two or three strokes in an upward direction to make sure that all valves are functioning; then discharge the contents into a clean and perfectly dry receptacle, preferably of glass, as C.T.C. will attack enamel. Lightly grease the plunger rod and wipe off. Recharge with the original contents, making good any loss from a fresh charge.

Use. The C.T.C. extinguisher is not recommended for fires in " free burning " materials, *i.e.*, wood, textiles, paper, rubbish, etc., but if necessary it will give reasonably useful service. It is not recommended because other types are better adapted and because of the difficulty of confining the vapour to the seat of the fire. For liquid fires it should only be used in the incipient stages when the depth of the inflammable liquid is slight. Where a considerable depth is present, the jet of liquid C.T.C. passes through the flames without vaporising sufficiently to produce an atmosphere which will not support combustion and since C.T.C. will mix with most liquids in this class, it promptly distributes itself throughout the fuel. In the case of petrol, for instance, it would require 70 per cent. of C.T.C. to 30 per cent. of petrol before the latter would cease to burn.

For electrical fires it may safely be used because it is a non-conductor.

For fires in motor vehicles C.T.C. extinguishers are of outstanding value. In this class the majority of fires occur under the bonnet, where the C.T.C. vapour is caught in a confined space whilst the operator remains in the open air. The extinguisher is small and readily brought into operation. For tank wagons, etc., other types (such as foam) may be preferred, but for general motor vehicle use the C.T.C. extinguisher holds first place.

It is a strong solvent of grease and fats and, owing to its relatively low boiling point (which means that it evaporates rapidly) and the fact that it is relatively inert, its use does not result in damage to fabrics, etc.

C.T.C extinguishers should, under no circumstances, be used on incendiary bombs.

(b) Methyl Bromide Extinguishers. Investigation has shown that methyl bromide, which is a stable colourless liquid with a boiling point of 40·3° F., and which upon release to atmosphere at normal temperatures rapidly evaporates, possesses excellent fire extinguishing properties. Methyl bromide has the very low inhibitory factor of approximately 3·5 per cent., whilst the vapour is 3·27 times heavier than air. It is ejected from its containing cylinders at a low pressure in liquid form by added pressure through the medium of an inert gas, hand extinguishers being charged to a pressure around 50 lbs. per sq. in. Discharge is assisted in some measure by evaporation of the liquid on the release of pressure. One lb. of methyl bromide will produce 3·7 cu. ft. of gas. This gas is toxic, and if inhaled in a concentration and for a sufficient time is capable of causing death. The toxic gases produced are small quantities of hydrobromic acid, bromophosgene, possibly only momentarily, and free bromine.

Methyl bromide hand extinguishers consist essentially of a bottle-shaped container which is charged with methyl bromide at about 50 lbs. pressure, and sealed with a metal disc. The container is usually made from seamless drawn copper. The extinguisher is operated by means of a plunger which pierces the disc and allows the liquid to emerge in the form of a powerful jet.

Methyl bromide extinguishers are classified in sizes according to the weights of their contents, which vary from 8 ozs. to approximately 8 lbs. Three principal types are manufactured:—

(i) The total discharge type.
(ii) The controlled discharge (plunger) type.
(iii) The controlled discharge (valve) type.

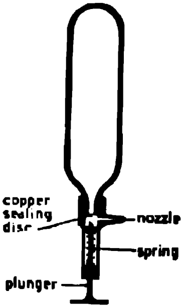


Fig. 11. Section through total discharge type methyl bromide extinguisher, showing plunger in base of extinguisher.

(i) *The Total Discharge Type* (Fig. 11) has a plunger in the base of the extinguisher which pierces a copper sealing disc. The whole of the contents of the extinguisher must be discharged whenever it is operated.

(ii) *The Controlled Discharge (Plunger) Type* (Fig. 12, *left*) operates on the same principle, but is fitted with a spring-loaded plunger (*a*), held in position by a safety pin (*b*), and a trigger control (*c*). Removal of the pin releases the plunger which is driven through the sealing disc (*d*) by the spring and at the same time the mouth of the cylinder is sealed by means of the shoulders (*e*) on the plunger which rest on a seating until it is withdrawn by raising the trigger control (*c*). This type has the advantage that it can be shut off as soon as the fire is extinguished thus reducing the danger from toxicity and also effecting a considerable saving in the cost of recharging. The extinguisher can be used again after partial discharge—if a flashback from the fire occurs for example, or on subsequent fires—but as a perfect seal is not obtained once the disc has been pierced, the extinguisher must be returned to the makers for topping-up and re-sealing as soon as possible after use.

(iii) *The Controlled Discharge* (*Valve*) *Type* (Fig. 12, *right*) has no copper sealing disc. It is fitted with a wheel valve (*a*) and a cock (*b*) on the discharge tube (*c*) at the top of the extinguisher. The extinguisher is operated by turning the wheel anti-clockwise and opening the discharge cock. The valve fitted on this type provides a perfect seal if screwed down hard, and the extinguisher can therefore be used as required. The amount of liquid remaining can be ascertained by weighing.

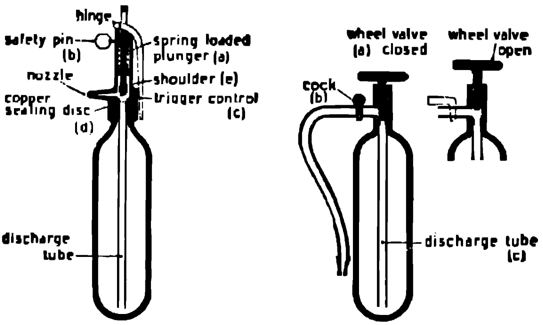


Fig. 12. Sections through controlled discharge type methyl bromide extinguishers. Left : plunger type. Right : screw-down valve type.

Use. Methyl bromide, like C.T.C., is a non-conductor of electricity, and is used principally for dealing with electrical fires and those types of fire for which C.T.C. would prove suitable. It is used both in the form of portable extinguishers and in fixed installations, being principally employed for protecting transformers, etc., and high risk industrial stores, such as stocks of paint, oils, etc. It is also very widely used for aircraft and small boat protection.

Testing. The extinguisher is tested periodically by weighing. The weight of the container in pounds and ounces is stamped on each extinguisher and the accurate net weight of the contents is stated by the manufacturer for each size. If the total weight of the extinguisher when weighed is less than these two figures combined, then the extinguisher should be returned to the makers for recharging. It is claimed, however, that these extinguishers will retain their contents intact for ten years from the date of charging.

Advantages and Disadvantages. The advantages of the methyl bromide type of extinguisher are :—

(i) It is extremely rapid in operation.

(ii) Being 3·27 times heavier than air the vapour is less easily affected by convection currents and draughts from extraneous causes.

(iii) A 5 per cent. concentration will extinguish the majority of fires in confined spaces, and relatively small and compact extinguishers can therefore be used.

(iv) Small hand extinguishers are light in weight and can be operated with one hand, leaving the other hand free.

(v) It will not harm fabrics or other delicate materials.

(vi) It is a non-conductor of electricity.

The disadvantages are :—

(i) It is comparatively costly.

(ii) The vapour is toxic.

(iii) It must be returned to the makers for recharging.

(iv) There is no visible check on the contents, the presence of which can only be ascertained by weighing.

The methyl bromide hand extinguisher is not widely used in the Fire Service, owing principally to its high cost, but in some localities a number of these extinguishers have been carried, largely experimentally and generally in substitution for the C.T.C. extinguisher.

(*c*) *Carbon Dioxide Extinguishers.* Whilst carbon dioxide (CO_2) as an extinguishing medium is widely employed in fixed installations it is also frequently to be found in portable form.

As a firefighting medium it functions, in the same way as C.T.C. and methyl bromide, by partially excluding oxygen. The release of the gas at high velocity may also help to beat out the flames.

CO_2 is a gas at ordinary temperatures but when compressed for storage in cylinders, it liquefies. When released the liquid vaporises, the rapid expansion lowers the temperature, and part of the gas is solidified in fine particles. Whilst the cooling effect may play some part in extinguishment it should be emphasised that it is the exclusion of oxygen which is of primary importance.

CO_2, which is a colourless, odourless gas, is not poisonous, but, being a non-supporter of combustion, when inhaled in large quantities leads to suffocation. Physiologically in very small quantities it stimulates respiratory action and is administered with oxygen in resuscitation. (See Chapter 12.)

CO_2 hand extinguishers are available in cylinder sizes having capacities of from 2 lbs. to 12 lbs. of liquefied gas.

The extinguisher (Fig. 13) consists of two principal parts, a steel cylinder (*a*) containing the liquefied gas fitted at the top with a sealing disc and piercing or valve mechanism (*b*) and a metal fibre or composition horn or distributor (*c*) which in the smaller models is rigidly connected to the valve mechanism and in larger sizes is connected by flexible high pressure hose (*d*). The cylinder is usually filled to approximately two-thirds by weight of its total water capacity. The disc may be pierced in some models by knocking in the plunger at the head of the cylinder and in others by a lever device, or the gas may be released by opening the valve.

The essential feature about this valve, whatever its type, is that it should open quickly and provide a clear passage for the liquid. If this free passage does not exist " wire drawing " takes place and freezing up of the valve occurs. For this reason the small orifices usual in commercial valves are unsuitable. The discharge mechanism

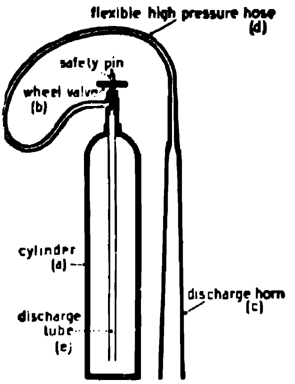


Fig. 13. Section through CO_2 extinguisher, showing discharge tube, piercing mechanism and discharge control valve.

is usually designed so that the entire contents are ejected in approximately one minute.

Owing to the expansion of the discharging gas and its liability to freeze, careful design of the discharge mechanism is essential. A discharge tube (*e*) is fitted to the cylinders so that liquid CO_2 is released through the valve in the cylinder head. Expansion may commence in the flexible hose but the greater part of the process takes place in the discharge horn which is used to direct the gas on to the seat of the fire. The ratio of expansion is approximately 450 to 1. The design of the discharge horn is a most important feature of CO_2 extinguishers. Its main duty is to stop the entrainment of air with the CO_2 and to reduce the velocity of the CO_2. Without this horn the jet of CO_2 acts like a blow-torch and will by its velocity increase the intensity of the fire.

The flexible hose should always be of the high-pressure type, since the contents of the cylinder are held under a pressure of 744 lbs. per sq. in. at 60° F., and this pressure is transmitted to the hose on discharge. At temperatures higher than 60° F. the pressure increases and may reach 2,000 lbs. per sq. in.

A subsidiary valve for shutting off the flow of gas temporarily is sometimes fitted at the entrance to the horn. Where these extinguishers are carried on brackets some makers so arrange the bracket that a discharged cylinder cannot be replaced in position.

Testing. CO_2 extinguishers in use by the Fire Service are tested six-monthly by weighing. Each extinguisher is carefully weighed on receipt and the weight recorded. If a loss of more than 10 per cent. is recorded the extinguisher should be returned to the makers for recharging. All cylinders made to Home Office specification are tested hydraulically to a pressure of 3,375 lbs. per sq. in., the bursting pressure being in the region of 7,000 lbs. per sq. in. The sealing discs used by one firm of manufacturers are designed, as a safety precaution, so that they will rupture automatically if the pressure exceeds 2,700 lbs. per sq. in.

Advantages and Disadvantages. The chief advantages of CO_2 as an extinguishing agent are :—

(i) It is extremely rapid in action and its action is independent of atmospheric temperature.

(ii) Cleanliness. Being an inert gas, it quickly disperses, leaving no trace behind. It has no chemical action under normal conditions, and no damage is caused by its use except possibly that in certain circumstances the intense cold produced might have, apart from fire damage, some effect on articles coming into close contact with the main body of the discharging gas.

(iii) It is a non-conductor of electricity. This, combined with its cleanliness, makes it of particular value in fires involving electrical apparatus.

(iv) It may be used in their incipient stages on fires in a number of highly inflammable liquids such as methyl, ethyl and butyl alcohols, acetone, amyl acetate, ether, carbon disulphide, etc., which it does not contaminate as would foam.

(v) Being a gas, it will penetrate into otherwise inaccessible positions.

The chief disadvantages are :—

(i) The total weight of the extinguisher in comparison with the weight of gas discharged, is considerable. Thus with a typical small hand CO_2 extinguisher the gross weight is 10¾ lbs. for a capacity of 2 lbs. of CO_2, and the next size model has a gross weight of 27 lbs. for a capacity of 4 lbs.

(ii) There is no visible check on the contents. Extinguishers must be accurately weighed at regular intervals to ensure that no leakage has taken place.

(iii) They must be sent away for recharging.

It should be noted that CO_2 extinguishers cannot be used on magnesium type incendiary bombs as the metal will burn as readily in this gas as in air.

4. DRY POWDER EXTINGUISHERS

At one time dry powder extinguishers were widely employed by the general public, but owing to their very limited effectiveness they have been superseded by more effective media. These powders were frequently contained in tins held on brackets. The action of removing the tin from the bracket opened the mouth through which the powder could be thrown on to the fire by the operator. In other types the container had a frangible seal or was itself readily broken when thrown forcibly at the fire. A number of methods of forcibly ejecting powders from their containers have also been employed such as by using small cartridges of compressed CO_2, charges of gunpowder, etc. Whilst the action of this powder was supposed to smother the flames, the principal effect obtained was to knock them out. The incendiary bomb menace has caused the attempted exploitation of these types once again. The composition of the powder itself varies with the different proprietary types of extinguisher. Many patents have been issued, covering variants of the same basic principle, each of which is alleged to possess advantages which place it above all others.

Until comparatively recently at least 95 per cent. of powder extinguishers contained a mixture of sodium bicarbonate with an inert material such as precipitated chalk, whiting, sand, sawdust, or dry clay. The sodium bicarbonate formed the extinguishing material, being in proportion of from 45 to 95 or more per cent. of the total contents of the extinguisher, the other substance or substances being added to prevent the mixture caking in the unused container, due to absorption of moisture.

One formula for this type of powder consists of :—

Sodium bicarbonate	97	per cent.
Magnesium stearate	1½	,,
Magnesium carbonate	1	,,
Tricalcium phosphate	½	,,

This is the formula used by a large firm of extinguisher manufacturers in America.

Although a small quantity of carbon dioxide gas is given off when this mixture is applied to heat (only about 4½ cu. ft. for 1 lb. of the material) the main extinguishing effect is that of direct smothering, and its use is therefore confined to cases in which the fire can be approached sufficiently closely to enable enough powder to be thrown down to cover the burning surface.

These powders came into prominence during the first World War and were so widely advertised as effective media for dealing with incendiary bombs that the Secretary of State appointed a Committee in 1916 to test their value. The Committee decided that the powders had a slight value as first-aid appliances, but were not noticeably more efficient than water. In the course of his evidence before the Committee, the then Chief Inspector of Explosives stated that these powders " merely consist of a few pennyworth of bicarbonate of soda, or a mixture of bicarbonate and chalk. They are practically of no more value than so much sand and are less effective than a bucket of water."

The Royal Commission on Fire Brigades and Fire Prevention (1923) quotes this finding, and advises that these mixtures are not to be recommended for general use.

Experiments have been made in recent years, however, which have resulted in improved forms of these powders (although the old forms still persist). Particular attention has been paid to the development of suitable powders for attacking fires involving magnesium and other light metals, and the advent of war, with the threat of damage from incendiary bombs, has done much to speed this development.

Several materials have now been produced and patented which undoubtedly, from impartial tests, exercise a restraining influence on incendiary bombs and may in some fortunate cases where the bomb has fallen on an incombustible surface extinguish it entirely.

One such powder consists of " a mixture of loose asbestos fibres with powdered graphite or siliceous material with a smaller percentage of anhydrous magnesium chloride and calcium fluorite." This mixture is used in conjunction with sodium bicarbonate.

Another, more recent, formula developed purely for dealing with incendiary bombs, consists of a mixture of borax, magnesium carbonate, fire cement, alum, and blacklead. This mixture results in a grey powder, which is converted by the heat of the bomb into a viscous black fluid. This fluid is claimed to seal the unburned parts of the bomb and prevent further combustion, as well as excluding all oxygen from combustible materials near and under the bomb.

Perhaps the best known of these patented powders, and one which is widely used in factories dealing with light metals, is composed of a mixture of bitumen, slate powder and aluminium stearate, in the following approximate proportion: bitumen 45 per cent., slate powder, 45 per cent., aluminium stearate 10 per cent.

This powder has achieved considerable commercial success owing to the fact that it protects the unburnt metal from further damage, and enables it to be salvaged in good condition.

Few of the powders produced or advertised, except those developed for protection against the highly specialised risks mentioned above, are of any practical value, though many variants of sodium bicarbonate powders are still marketed. It should be emphasised that their value for general household use is negligible and their provision may lead to a false sense of security. They are of no practical value whatsoever for dealing with incendiary bombs.

When employed for special risks their effect is purely local, and they are quite useless for dealing with subsequent fires on any scale, which must be fought with the appropriate equipment.

5. EMULSIONS

A considerable amount of research has been devoted to developing a suitable heavy blanketing medium for dealing with fires in such substances as magnesium.

Several patents have been granted in the last three years, the principle in each case being the use of an emulsion made from a mixture of water, an oil having a high flash point, and some soluble silicate such as water glass. In some formulæ substances which produce an extinguishing gas, such as ammonium carbonate, methyl or ethylene bromide, are added to assist the action.

These emulsions have proved successful in extinguishing small fires involving magnesium and other light metals, but their application to fires caused by incendiary bombs is subject to the same disadvantages as the powder extinguishers.

Although these developments of known principles may have some valuable industrial applications, their use is not to be recommended for the general public, and they are still too experimental to be adopted by the Fire Service.

CHEMICAL ENGINES

Larger types of portable extinguishers which can be wheeled into position are known as chemical engines. They may be either soda-acid, foam, methyl bromide, or CO_2 types. They are rarely used by the Fire Service but will be found in many industrial premises, institutions, etc. These extinguishers range in capacity from 10 to 30 or occasionally 50 gallons of fluid, and the reaction which leads to the discharge of the contents is produced in precisely the same manner as in the smaller hand extinguishers.

The soda-acid and foam type extinguisher body (Plate 6) is well balanced on wheels and is moved into position in an upright or semi-upright position by handles. Chemical engines for indoor use are usually equipped with an extra narrow track to pass through doorways, etc. A length of hose, usually 30 ft., is employed with nozzles ranging up to ½ in. diameter for the soda-acid type and ¾ in. for the foam type. CO_2 cylinders are fitted with discs and releasing gear just as in the hand types and the methyl bromide types usually consist of several ordinary large extinguishers coupled together. The nozzle when employed is usually fitted with a cock to shut off the flow and prevent water damage. Some models are fitted with a pressure gauge.

To operate the soda-acid and foam types the engine should be wheeled within striking distance of the fire and kept upright. The hose should then be run out with the nozzle cock closed. The valve in the head should be unscrewed and the handles lowered to the ground thus laying the extinguisher on its side. With some models the body of the extinguisher is pivoted so that it can be reversed to actuate it. A period of ten seconds should elapse before the nozzle cock is opened. When the engine is half discharged it should be rocked to agitate the contents.

After use the whole interior should be carefully washed out and the engine recharged, taking the same precautions as when charging the appropriate type of hand extinguisher.

CO_2 and methyl bromide chemical engines are operated in the same way as hand extinguishers of these types, and must of course be returned to the makers for recharging.

EXPLOSIONS IN FIRE EXTINGUISHERS

No definite statistics are available in this country on how many explosions have occurred in soda-acid hand fire extinguishers, and to what those which have occurred were due. The National Fire Protection Association Transactions for April, 1939, however, list nine reported extinguisher explosions in the U.S.A. in the nine years 1930–38. Cases in which extinguishers have exploded have been due to

1. Use of extinguishing material or charges other than those as supplied by the manufacturers or not in accordance with the correct standard.
2. Defective threads on the cap or a failure to replace the correct cap on the right extinguisher where more than one was being recharged at the same time.
3. Repairing defective extinguishers instead of replacing them.

One case of an extinguisher explosion in this country was due to the outside container which was made of copper having been polished regularly. This polishing over the course of years so weakened the outer shell by removing metal that when put into operation it exploded, a weakness which regular pressure testing would have revealed.

The explosion risk should virtually be non-existent, since if the extinguisher is designed to the requirements of British Standard Specification No. 138, and the correct charges are used, excessive pressures cannot be built up inside, even when the nozzle is blocked. Regular pressure testing will ensure the soundness of the main container.

PART I CHAPTER 10

FOAM AND FOAM-MAKING BRANCHES

THE principal method of fire extinction employed by the Fire Service is to cool the temperature of the burning materials below their ignition point by the application of water in the appropriate volume, in the form of a jet or a spray depending on the type of fire. Some of the most hazardous substances from the angle of fire risk, however, are liquids having a specific gravity lower than that of water.

When water is applied to the burning surface of such a liquid it lowers the temperature momentarily and then sinks below the surface, where any further effect is lost except in the case of substances such as methylated spirit which mix freely with water. Dilution may in this case take place to the point where combustion cannot further be maintained, but, as this involves a great increase in volume, it is not always possible (the burning liquid may overflow, for example) and the destruction of potentially salvageable property is to be deprecated.

Whilst the momentary cooling may sometimes result in extinguishing the fire the effect is normally too short-lived, and combustion continues, although for certain types of risks high-pressure water projected on to the surface of the burning fluid may emulsify or break up the burning layer and so cool and separate the combustible material that the fire is extinguished. The application of this principle is dealt with in the Chapter on " Sprinklers, Drenchers and Waterspray Systems."

It has been shown in Chapter 2 that one of the methods which can be employed for fire extinction is smothering or the limitation of oxygen. Many years ago it was shown that if an acid salt such as aluminium sulphate is allowed to react with sodium bicarbonate in a solution to which a small quantity of a stabiliser has been added then a frothy product is obtained which retains its texture for a comparatively long time. This froth is relatively insoluble in most liquids and, owing to its light weight, floats on the liquid. When applied in sufficient quantities it forms a blanket capable of covering the surface of the burning liquid and extinguishing the flames by cutting off their contact with the air. This froth, or " foam " as it is termed, is composed of masses of small bubbles of carbon dioxide, and owing to the method of its formation is known as " chemical foam."

A very great amount of research work has been carried out on the production of foam, and it was discovered that if suitable compounds were added to water which was then violently aerated a foam very similar in its general properties to chemical foam was produced. The bubbles were, however, filled with air and not carbon dioxide. This has been proved not to affect the extinguishing properties of foam since the action is essentially one of blanketing and the carbon dioxide in the bubbles of chemical foam plays little part in the reaction. Foam produced in this manner is called "mechanical foam" or sometimes " air foam."

Experience has shown that the most satisfactory mechanical foam is one which has an expansion ratio of about 8 ; *i.e.*, when the volume of foam produced is eight times that of the water used.

CHEMICAL FOAM

1. COMPOSITION

Chemical foam is relatively little used by the National Fire Service and has been replaced almost entirely, except in hand extinguishers, by mechanical foam. Chemical foam is, however, frequently used in fixed installations for the protection of oil refineries, storage depots and similar risks. Chemical foam is normally produced by the interaction of aluminium sulphate with sodium bicarbonate in solution, to which a stabiliser is added. The exact composition and proportion of this stabiliser varies according to the patents of the manufacturer and is frequently kept as a trade secret. Liquorice, turkey-red oil, saponine, extract of soap bark or *quillaja saponaria* and albumen are amongst the substances used.

The stabiliser takes no part in the chemical reaction, but strengthens the walls of the individual bubbles and prevents them bursting. It is believed that the aluminium hydroxide formed during the reaction may also play some part in assisting this strengthening. When used in chemical hand extinguishers the two principal ingredients are stored as separate solutions which are mixed when the extinguisher is operated. Bubbles of gas are formed throughout the liquid and the whole container is filled with foam which is ejected by the gas pressure set up by the CO_2 generated.

2. CREATION OF CHEMICAL FOAM

When larger quantities of chemical foam are required than are provided by the hand extinguisher either a chemical engine or some form of continuous foam generation must be employed. The principle of working of the chemical engine is precisely the same as that of the hand extinguisher but on a larger scale, and has been dealt with in Chapter 9.

Large quantities of chemical foam may be produced in one or other of two ways :—

(*a*) By bringing together, as required, solutions of the two ingredients which, on mixing, produce foam ; or

(*b*) by introducing into a hose line the two main ingredients in powder form. In the presence of water the powders dissolve, chemical action ensues and foam is generated.

(*a*) *Mixing of Foam Solutions.* The former method is but little used by the Fire Service, but may be encountered on some types of airport crash tenders, since the production of foam by this method is almost instantaneous and it can be made available, particularly in conjunction with hose reels, in minimum time.

The amount of foam produced is governed by the liquid carrying capacity of the vehicle.

The liquids are pumped separately from their containers into a common hose line, the turbulence involved in passage through the latter ensuring thorough mixing. A standard branch with a nozzle diameter usually of 1½ ins. is employed to direct the foam on to the fire. A positive displacement pump with two cylinders, one for each solution, is employed, since the liquids must be mixed in their correct proportions, usually 1 to 1, the respective strengths being suitably adjusted.

(b) Foam Generators. The respective constituents in powder form occupy considerably less space and weight than when in solution. Where water is available locally, therefore, the method of introducing the chemicals into the hose line and allowing them to dissolve and react therein has been developed. The advantage of this method compared with that described in (*a*) above is that the generation of foam can be made continuous and is only limited by the availability of water and the necessary chemicals. Any Fire Service pump and standard hose and equipment can be used, the necessary special equipment being limited to a device for introducing the powdered chemical into the hose line.

Since the chemical action only takes place when the chemicals are wet or in solution they may be kept mixed together ready for use in airtight drums provided precautions are taken against damp. This method of producing foam is known as " continuous foam generation " and the special equipment used for introducing the chemicals into the hose line a " foam generator."

Foam generators are of two main types : (i) intermittent, and (ii) continuous.

(i) *Intermittent Type.* A typical generator of this type consists of a cylindrical container (Fig. 1, *left*), which is fitted with couplings

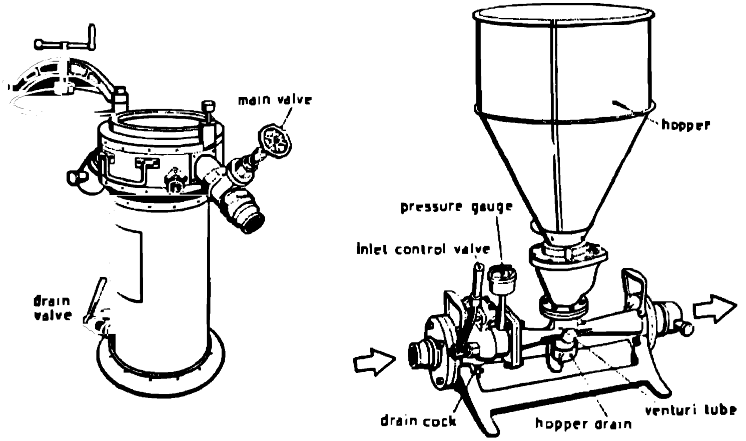


Fig. 1. Chemical foam generators. Left: Intermittent type, showing lid open ready for the insertion of a charge. Right: continuous type.

for connecting into the hose line in use. A charge of powder is deposited in the cylinder, the lid screwed down, and the main valve opened to allow water to be passed through. When the powder is exhausted the water must be shut off, the lid opened, a fresh charge of powder inserted, the lid closed and the water again turned on. Before inserting the fresh charge, however, the drain valve should be opened to allow the cylinder to drain, and re-closed. The process may be made more nearly continuous by having two generators connected in parallel so that one may be in use whilst the other is being charged.

(ii) *Continuous Type.* In this type (Fig. 1, *right*) an injector device (see Chapter on "Hydraulics") with a hopper above is connected into the hose line. Foam powder is tipped into the hopper and the water turned on. So long as the supply of chemical is maintained the generation of foam is continuous.

Since the reaction which generates the foam is initiated immediately the chemicals enter the water stream the generator must be placed close to the branch, usually about 100 ft. away. Any greater distance causes undue friction in the hose and may tend to break down the foam whilst a lesser distance does not permit of the thorough mixing of the charge with the water stream. In order to reduce friction and minimise breakdown in the foam, rubber-lined hose should be employed whenever possible, although satisfactory results can be obtained using unlined hose.

A typical powder foam generator of this type (Fig. 1, *right*) consists of an injector device mounted on collapsible metal legs and fitted with a removable copper hopper. Male and female couplings are provided for it to be inserted into the hose line, and a pressure gauge is fitted on the incoming side to enable the operator to see the water pressure at the generator, which should be approximately 100 lbs. A simple control valve is fitted, having a lever so arranged that sudden closure is impossible. The base of the valve is fitted with a drain cock to prevent freezing in frosty weather. The complete apparatus weighs approximately 72 lbs.

There are several larger sizes of this type of generator, the principle of construction being the same in each case, but on a larger scale, the internal nozzles being of different cross-sectional areas.

With installations of this type the greater the water pressure, the greater the foam output, since more water is passing through the apparatus and more powder is necessarily being taken into the stream. The volume of foam produced for a given quantity of water is considerably greater than that obtained from mechanical foam. With the apparatus described above, 750 g.p.m. of foam are produced from 54 g.p.m. of water at 100 lbs. inlet pressure. A comparable mechanical foam apparatus produces 450 g.p.m. of foam. With the chemical type of foam it is the richness of the mixture which governs the quantity of foam produced for a given quantity of water, and equivalent results in foam production can therefore be obtained from much smaller quantities of water, resulting in a foam which is lighter than that produced by the use of foam compound (*i.e.*, mechanical foam).

This advantage is, however, offset by the fact that :—

(*a*) The generator must be placed very near the fire, which particularly when working on oil fires is often undesirable, and

(*b*) the weight of powder consumed is very considerable, and might cause transport difficulties if the apparatus were used at any distance from a source of supply. As an example of the actual weight involved, the apparatus described above, when producing 750 g.p.m. of foam, requires 105 lbs. of powder per minute, or approximately 2¾ tons per hour. For this reason oil installations and other premises at which powder generators are employed usually carry a very large standing stock of foam powder.

With either of these types of chemical foam generator normal equipment (*i.e.*, hose and branches) may be used, but a nozzle of 1½ ins. to 2 ins. diameter is required.

MECHANICAL FOAM

It has already been explained that by introducing a suitable compound into the water stream and then aerating the resulting mixture a stable foam can be produced. This basic principle applies irrespectively of the size of the equipment or the purpose for which it has been designed. To produce mechanical foam the following major items of equipment are required :—

(i) A pump for imparting the necessary energy to the water (this may be any suitable Fire Service pumping appliance) or (with certain types only) a hydrant with a pressure of at least 70 lbs.;

(ii) Hose for delivering the water where required ;

(iii) A means for injecting the foam-making compound or " foam compound," as it is called, into the water stream ;

(iv) A means of aerating the resulting mixture and apparatus for projecting the resulting foam on to the fire.

(iii) and (iv) are sometimes carried out by the one piece of equipment known as a " foam-making branch."

1. COMPOSITION

Foam compound is a proprietary mixture, the composition of which, as with chemical foam powders, varies with the patents of the manufacturers. There are three main types in use. Of these the first comprises various forms of liquid soap, the second is a sulphonated compound, and the third, which is the type issued to the Fire Service, is a protein compound. It is injected into the water stream either by means of an injector device contained in the foam-making branch itself, or by a special piece of equipment known as an inductor, and directed on to the fire by the branch.

Foam compound must be kept in the sealed cans and drums in which it is supplied until actually required for use. It must not be decanted for storage. If decanting is necessary when foam is required at a fire, the receiving container must be perfectly clean and should be marked so that any unused fluid is reserved only for practice work. When foam compound is being poured into the tank of an inline or multiple jet inductor it should, if possible, be strained in order to prevent the sludge or crystalline matter which accumulates at the base of the tin or drum being poured into the tank and possibly blocking the inductor pipe. Although straining may not be practicable, precautions should always be taken to prevent more than is unavoidable of this sludge getting into the tank. The compound should not be shaken or disturbed before pouring, and the tin or drum should not be completely drained. To obviate confusion between 2-gallon tins of compound and petrol, the former should be marked with a large " F " on each side and a piece of cord or rope tied round the handle for identification by touch in the dark.

Foam compound for use in No. 2 foam-making branches is normally supplied in 2-gallon tins. These have the advantage that they can readily be lifted to fill the knapsack tank on the branchman's back. For use with small inductors 5-gallon drums are of convenient size, whilst for use with the larger inductors 20-gallon drums are available. The illustration of the multiple jet inductor (Fig. 9) shows a 20-gallon drum in position for filling the tank.

As was explained above, there are three main types of foam compound. More than one type of compound should never be employed at the same fire, as the different chemical compositions would result in each foam breaking the other down. Mixture of different types of compound before foam formation is also to be avoided, as this causes the precipitation of a sludge which may cause jets and strainers to become clogged. Even if this precipitation is not serious in its consequences, the resulting liquid will in many cases not produce a stable foam on aeration.

Experience at recent oil fires has shown that chemical and mechanical foam can, however, be used together without breakdown occurring. It is, none the less, advisable whenever possible to avoid mixing any two types of foam, and the usual practice where both powder and foam compound are in use is to confine the foam produced by each type to different parts of the operations so that no mixing occurs.

In order to obtain satisfactory results with foam-making equipment, scrupulous cleanliness is essential. Furthermore, if a practice solution has been used in any apparatus, such apparatus must be thoroughly cleansed immediately after use.

Whenever the apparatus has been in use it must be emptied of any remaining foam compound and washed in clean water. As foam compound oxidises on exposure to air, forming a skin, it must not be poured back into the drum, but must be set aside for practice purposes as should the remainder in any open drum. Once a drum of foam compound has been opened it cannot be kept for use on a fire at a later date.

2. CREATION OF MECHANICAL FOAM

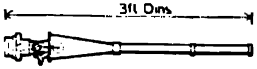
There are two methods of creating mechanical foam :—

(*a*) By means of a special branch known as a foam-making branch, which is used in conjunction with a fire pump and some form of injector.

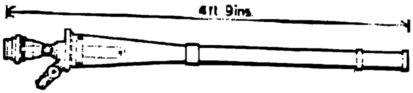
(*b*) By means of a special pump which both mixes and aerates the foam compound and water, a normal branch being used.

The former of these methods is that used in the National Fire Service.

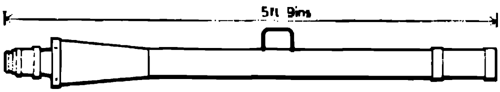
(*a*) *Foam-making Branches.* Four sizes of foam-making branch are in general use (Fig. 2) in the National Fire Service, and since the method employed for introducing the foam compound into the water stream varies with the size, each will be dealt with separately. The sizes are :—



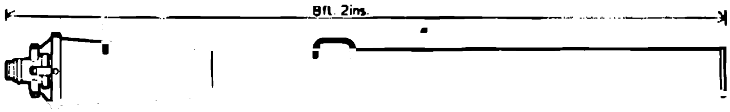
No. 0 F.B. 12 g.p.m. of water at 100 lbs. per sq. in. + ¼ to ⅜ g.p.m. of foam compound gives 96 g.p.m. of foam.



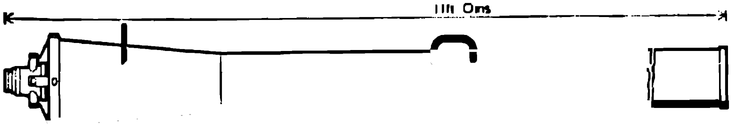
No. 2 F.B. 50 g.p.m. of water at 100 lbs. per sq. in. + 1¼ to 1¾ g.p.m. foam compound gives 450 g.p.m. of foam.



No. 10 F.B. 100 g.p.m. of water at 100 lbs. per sq. in. + 3 g.p.m. foam compound gives 800 g.p.m. of foam.



No. 20 F.B. 200 g.p.m. of water at 100 lbs. per sq. in. + 6 g.p.m. foam compound gives 1,600 g.p.m. of foam.



No. 30 F.B. 300 g.p.m. of water at 100 lbs. per sq. in. + 9 g.p.m. foam compound gives 2,400 g.p.m. of foam.

Fig. 2. Foam branches.

Branch size
No. 2
No. 10
No. 20
No. 30

There is also a smaller size known as the No. 0, but as this is of limited value owing to its small capacity it will not be described here. It is used with the first-aid outfit and works on the same principles as the No. 2 model.

(i) *The No. 2 Foam-making Branch and Knapsack Tank.* The No. 2 size may be taken as the first example as it is the most generally used model. In Fig. 3 is shown its general appearance, with knapsack tank and compound suction hose, and in Fig. 4, its working principles.

The knapsack (Fig. 3), (*a*), which is used as a container for the foam compound, is carried on the back of the operator, has a capacity of 4 gallons and is fitted with a quick-release cover (*b*) which permits rapid replenishment. The cock (*c*) on this tank is for convenience when assembling or dismantling the equipment. The cover is provided with two vent holes which must be kept clean at all times, otherwise when the compound is being fed to the branch access of air above the liquid in the tank will be checked and the flow will cease.

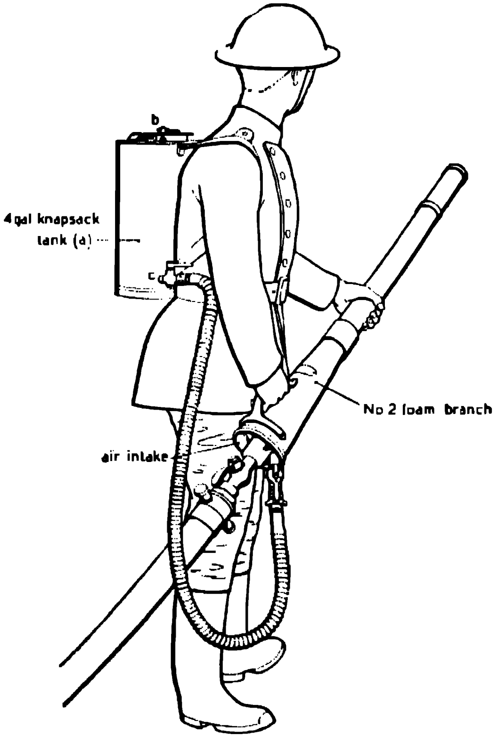


Fig. 3. No. 2 foam-making branch in action showing knapsack tank.

The foam-making branch (Fig. 4) may be divided into three principal parts, the water head at the base of the branch (*a*), the tapered mixing tube (*b*) and a cylindrical discharge tube (*c*).

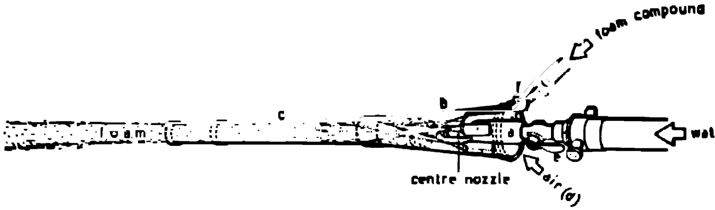


Fig. 4. Diagram showing mixing of foam inside a No. 2 foam branch.

The water head incorporates four water nozzles. Three of these are set at oblique angles so that the water from them issues in the form of a cone. In the centre of the water head is the fourth nozzle which contains an ejector. The water supplied to this nozzle passes through the ejector and draws the foam compound from the knapsack tank. This particular water stream thus becomes charged with a predetermined mixture of foam compound and water. The water and compound from this nozzle strike the apex of the water cone formed by the obliquely set nozzles, thus mixing the compound in the centre stream with the water from the three outer streams. The impinging jets break up into spray, filling the bore of the branch. As the spray moves at high velocity towards the discharge end a piston effect is produced which draws in air through the space (*d*) provided around the water head. This air mixes with the spray and the energy of the streams is used to produce the complete formation of foam. The main water inlet is provided with a cock (*e*) ; there is also a control cock (*f*) on the foam compound suction hose having three settings by means of which the consistency of the foam can be varied.

The foam compound cock governs the quantity of compound passed to the centre jet, which, like all ejectors, operates most efficiently over a definite known range. Ejectors are calibrated on the No. 2 cock setting, as this is the one most generally used.

(*a*) The No. 1 setting is apt to vary slightly in capacity because its orifice, being smaller than the No. 2, makes exact calibration difficult. It should be used for practice purposes only.

(*b*) The No. 2 setting produces suitable foam for oil and petrol fires. When dealing with petrol a moderate pressure will be found best, because the jet is then more easily controlled, there is less risk of splashing the spirit about and it is easier to obtain the foam covering blanket necessary to extinguish the fire. Where the longest possible jet is required, higher pressures would, of course, be used.

(*c*) The full-open setting produces a foam with more " body." This, however, does not present any advantage when dealing with oil and petrol fires, as the object of any foam, whether mechanical or chemical, is to flow easily over the burning area. This is best obtained by using the No. 2 setting as described above. Perhaps the best use for the fuller bodied foam is to act as a temporary fireproof covering for material surrounding the outbreak, whilst it is distinctly better when dealing with fires where alcohols and industrial solvents may be involved.

The No. 2 setting delivers 1¼ g.p.m. and the full-open setting 1¾ g.p.m. of foam compound.

The foam-making branch is thus under the complete control of the operator. When foam is required he opens both the water and the foam cocks. If water only is required he closes the foam cock. When the fire is out he shuts off the water cock, thus saving unnecessary water damage and eliminating the possibility of breaking down the foam blanket already formed.

Raising the water pressure increases the quantity of water used and, in proportion, the quantity of foam produced per minute, but does not proportionately increase the amount of foam compound used. Water pressure as high as practicable should be used as more energy is applied to the actual formation of the foam, giving better aeration, and also because higher pressure makes for longer jets.

The minimum water pressure at the branch for satisfactory operation with this model is 60 lbs. per sq. in. At 100 lbs. per sq. in. 450 g.p.m. of foam is produced. All figures which are given for foam production, however, should be taken as only an approximation. Variations occur according to the temperature of the water supply, its degree of hardness and the presence of foreign matter. Foam can be satisfactorily obtained with sea or brackish water.

(ii) *No. 10 Foam-making Branch.* It will be noted from Fig. 2 that from the No. 10 size upwards the reference number multiplied by ten represents the water capacity, or, multiplied by eighty, the foam production per minute. The percentage of foam compound used in normal operation is 3 per cent. in relation to the water employed, or 0·375 per cent. of the foam produced.

As the No. 10 model uses 3 g.p.m. of compound it will be seen that the use of a knapsack tank would be impracticable, and any alternative method of drawing compound direct into the branch from a container on the ground would greatly restrict the operator in his movements.

Other methods of introducing foam compound into the water supply are therefore employed for this and the larger sizes of foam-making branches. The items of equipment in most general use for this purpose at present are the inline inductor, the multiple jet inductor and the emergency pattern suction inductor.

When one No. 10 branch only is in use it is an advantage to operate from an inline inductor. When a larger number of branches is involved, or a larger size branch is employed, then a multiple jet or similar inductor should be used.

Since the inductors introduce the foam compound into the water stream before it reaches the branch, the No. 10 branch is not normally equipped with an inlet for foam compound.

In certain special cases, however, No. 10 branches have been fitted with such an inlet. A control cock similar to that used on the No. 2

branch is employed, but the length of the suction is considerably longer, being often as great as 15 to 20 ft. The jet arrangement on the normal No. 10 branch is similar to that of the No. 2 branch except that no centre jet with ejector is fitted, since the compound is already mixed with the water entering the branch. No command cock is fitted on the water inlet. The principles on which aeration takes place are identical with those which apply to the No. 2 model.

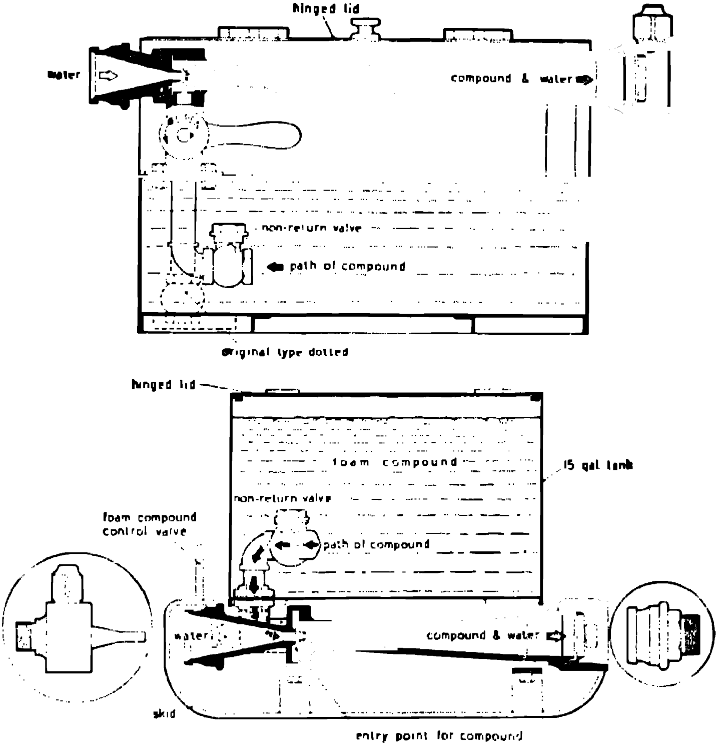


Fig. 5. Above. Section through earlier model inline inductor with inductor mounted above liquid level.
Below. Section through later model inline inductor on skids with adaptors for use if inductor is coupled to pump.

The Inline Inductor. The inline inductor takes advantage of the fact that the pressure energy of a water system can be converted into velocity energy, with a consequent reduction of the pressure. The pressure water in a line of hose is directed into the converging portion of the inductor (Fig. 5), where its velocity is sufficiently increased to ensure that at the throat a pressure is created below that of the atmosphere. This is the entry point for the foam compound, which is induced to flow along the suction pipe and, meeting the high velocity water jet, is carried forward as a combined stream into an expanding cone. Here its velocity is gradually reduced, with a consequent partial recovery of pressure, which pressure becomes available to operate the foam branch.

It will be seen that the pressure on the delivery side of the inductor must always be less than the inlet pressure, because of the work which has to be done on the foam compound in raising its pressure from that of atmosphere to the delivery pressure. There is also a certain hydraulic loss due to eddies and other disturbances set up as the water passes through the inductor.

The volume of water passing through the whole system is controlled by the size of the water jets in the foam branch at the delivery end of the system, combined with the line pressure existing behind those jets. The size of the throat on the inductor must be determined by this known volume of water to be handled, in order to obtain the velocity condition which will give a pressure below that of atmosphere. It will be realised, therefore, that an inline inductor must be used only with foam branches of the capacity for which it was designed, and the inline inductor issued to the National Fire Service should normally be used with the No. 10 foam branch only. It would, however, be quite practicable if necessity arose (such as the knapsack tank being damaged) to operate two No. 2 branches from an inline inductor, since the combined water and foam compound capacity of these would equal that of one No. 10 branch.

The inline inductor proper is mounted at the side of or below a foam compound tank (Fig. 6), having a capacity of 15 gallons. The whole piece of equipment is generally known as the inductor.

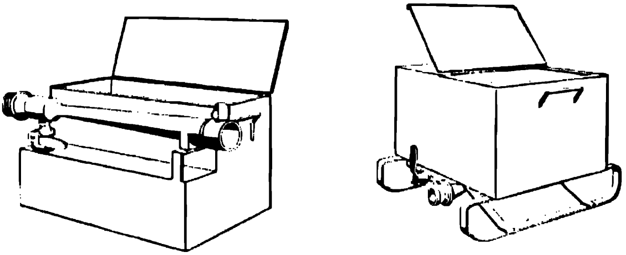


Fig. 6. Inline inductors. Left: old type. Right: new type.

When using the inline inductor there is a pressure drop across the inductor of approximately 35 lbs., which means that for full efficiency a water pressure of approximately 135 lbs. per sq. in. should be available.

To prevent water from the hose line flowing into the inductor tank in the event of unsatisfactory hydraulic conditions, a non-return valve is included in the suction pipe (Fig. 5). This was originally of mushroom type but has now been replaced by a flap-type valve which is unlikely to stick, a failing which is common in the former type, and is aggravated by the presence of sludge or grit in the compound.

On the underslung type of inline inductor the suction pipe has also been adjusted to give greater clearance from the bottom of the tank, so that possible accumulations of sludge or foreign matter in the tank will cause less trouble. A special fitting is used to convert the old mushroom-valve type inductors to the flap-valve type.

A pump capable of supplying 400 g.p.m. at a pressure of 135 lbs. per sq. in. would operate four inline inductors, producing, through four No. 10 foam-making branches, 3,200 g.p.m. of foam. The same pump could supply two inline inductors for foam production from one delivery valve of the pump whilst using the other delivery valve for water jets as required. This method of operation is, however, undesirable (since the pressures required at the foam branch and at the water jet may differ considerably) and should only be resorted to in an emergency.

To use the inline inductor—

(*a*) Connect into hose line as described above, with the inlet coupling towards the pump and the outlet towards the branchman; fill the tank with foam compound.

(*b*) Turn on water from pump.

(*c*) When water is flowing through the inductor, open compound cock.

(*d*) Keep inductor tank filled with foam compound.

Normally, the best average position in a water system for an inline inductor is 200 ft. back from the foam branch.

An inline inductor will usually function with anything between 300 and 600 ft. of hose between itself and the branch and working at this distance is in some circumstances an advantage, as it enables the bulk of the personnel to work at a safe distance from the fire. The quantity of compound which the individual inductor allows to pass varies, and the rate of consumption is sometimes so high that even with 600 ft. of hose in use it is still necessary to regulate the cock to bring the amount of compound consumed down to 3 per cent.

On the other hand, if the foam branch is to be used above ground level, *e.g.* on an upper floor of a building or at the top of an oil tank, the effect will be to reduce the amount of foam compound drawn into the line. This can be partially offset by increasing the pump delivery pressure or by inserting the inline inductor nearer the end of the line so that a reduction of friction loss between the inductor and the foam branch approximately compensates for the added delivery head.

It is not desirable to construct equipment requiring too many adjustments to cater for all possible variations in operation. Circumstances may arise which require special treatment, and the following hints may assist by indicating the line of action which can be taken by the well-trained operator.

One instance is where the inline inductor is exceptionally near the delivery end of the system and foam compound in excess of actual requirements is being absorbed. This will be observed by the rate at which the level of foam compound falls in the inductor tank. A rough computation can be made, if this is desired, from the fact that the tank is 15 ins. deep and contains 15 gallons. For the No. 10 size 3 g.p.m. should be used, that is, 3 ins. per minute. If the level is falling too rapidly, this can be corrected by partially closing the control cock.

(iii) *Nos.* 20 *and* 30 *Foam-making Branches.* The only difference between the Nos. 20 and 30 branches and the No. 10 described above is in size, and consequently in the quantity of water and foam compound consumed. The comparative sizes and consumptions can be seen in Fig. 2.

As the quantities of foam compound and water required by these branches are, however, too great to be supplied by an inline inductor, a larger type, known as the multiple jet or suction inductor, is employed to feed the foam compound into the water stream.

In some parts of the country a No. 30 elevating-type foam branch will be found. This is invariably used in conjunction with a large trailer pump. The compound can be induced into this model by means either of a multiple jet or similar inductor or an inline inductor with special adaptors to enable it to be used across the pump in the same way.

The arrangement of the inline inductor with these adaptors is shown in Fig. 5 (*below*), from which it will be seen that the conversion is a simple one, depending upon the provision of two adaptors, one on the inlet and one on the outlet.

The inlet adaptor (*inset, left*) converts the 2½ in. instantaneous inlet to 1-in. gas thread to which is coupled the 1-in. rubber hose leading from the delivery adaptor used with the multiple jet inductor (see later). The delivery adaptor (*inset, right*) converts the outlet to 1½-in. gas thread to which is connected the 1½-in. rubber hose leading to the suction adaptor.

The essential feature of this adaption is the provision of a reduced bore water nozzle as part of the inlet adaptor. This nozzle enters the standard water nozzle of the inline inductor and has the effect of reducing the water passing through the inductor from 100 g.p.m. to approximately 30 g.p.m., which is a reasonable quantity to by-pass round the pump.

THE MULTIPLE JET INDUCTOR. The working principle of the multiple jet inductor is identical with that of the inline inductor, but the inductor is not placed in the hose line, the necessary induction being obtained by abstracting a proportion of water under pressure from the delivery side of the pump, passing it through the inductor (where it is charged with foam compound) and delivering it into the suction side of the pump. The inductor is therefore located at the pump and is under the direct control of the pump operator.

In the head of the multiple jet inductor (Fig. 7) there is a nest of four small inductors each governed by its own control cock and each taking 7–8 g.p.m. of water. Therefore, when the pump delivery valve is opened, and also the valve on the adaptor on the pump suction, water circulates through the four inductors, and a by-pass circuit is created on the pump carrying 30 g.p.m. of water. In effect, approximately 30 g.p.m. of the pump capacity is being short-circuited (approximately 7 per cent. on a large trailer pump), in order to induce the foam compound into the system. It will be noted that it is well within the capacity of the large trailer pump to supply this 30 g.p.m. and at the same time to supply four No. 10 foam branches with the required water.

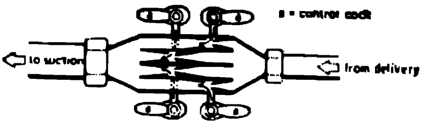


Fig. 7. Diagram of four-way inductor head.

The hydraulic conditions, therefore, across each inductor differ from those of the inline inductor in that the delivery cone delivers to the low pressure of the pump suction, instead of to the high pressure of the line.

It will be appreciated that if the pump were working on a suction lift, the foam compound would be drawn in automatically, without the aid of pressure water from the pump delivery. In fact a 5 ft. lift would cause the correct amount to be induced through the suction pipe, control cock, throat and delivery cone of each inductor. But the amount of the induction would vary with the lift, and obviously would be much in excess at 25 ft. lift.

To eliminate these variations automatically, connection is made to the delivery side of the pump so that the comparatively large pressure drop thereby available renders variation of the suction lift small enough to be negligible in comparison. The inductor can operate on positive pressures on the suction side up to 15 lbs. per sq. in. This positive pressure, however, should not be exceeded, or the amount of foam compound induced will be too small.

It will be realised that in using this type of inductor, all water passing into the pump from the suction will be loaded with foam compound when one or more compound cocks are opened, and, therefore, the pump will be delivering a stream of water with the correct admixture of foam compound. The small percentage of foam compound in the water passing through the cooling system of the engine will not affect its efficiency but will, of course, discharge to waste.

In these circumstances the pump cannot be used for delivering water to supply ordinary water jets unless all the inductor cocks are closed.

The inductor (Fig. 9) comprises a tank which may be of either 20 or 60 gallons capacity, to the top of which is fixed the unit which contains the inductors. Each inductor is equipped with an individual shut-off cock on the suction pipe which draws the foam compound from the tank.

The multiple jet inductors issued to the National Fire Service are calibrated to serve four No. 10 foam-making branches, in other words to charge up to 400 g.p.m. of water with the correct proportion of foam compound. This means that each inductor will draw 3 g.p.m. of compound from the storage tank. With a pump capable of delivering 400 g.p.m. of water at a minimum pressure of 100 lbs. per sq. in. four No. 10 branches can therefore be used simultaneously.

If, for instance, it is desired to use only one No. 10, then only one inductor control cock will be opened, the water head in the foam branch acting as a governor to the quantity of water delivered by the pump.

As the water head in the No. 10 branch will only pass about 100 g.p.m. at 100 lbs. per sq. in. nozzle pressure it follows that the pump will only be permitted to deliver 100 g.p.m., and, therefore, the 3 per cent. foam compound induced into the pump will be exactly sufficient to operate one No. 10 foam-making branch. From this it will be seen that, using a multiple jet inductor, any number of No. 10 foam-making branches from one to four can be operated.

Further, as has been explained above, the No. 20 branch requires 200 g.p.m. of water to feed it and the No. 30 requires 300 g.p.m. It will therefore be readily appreciated that the multiple jet inductor and one pump will operate two No. 20 branches or one No. 30 and one No. 10, because either of these combined alternatives requires a water delivery of 400 g.p.m. for the use of which all four inductor control cocks will have to be open. Carrying the example a stage further, if it is desired to operate one No. 30 foam-making branch, then three inductor control cocks will have to be opened, giving the required 9 g.p.m. of compound.

The multiple jet inductor should be got to work in the following manner :—

1. Fit the adaptors (Fig. 8) to the suction inlet and delivery valve of the pump respectively.

2. Connect the length of 1-in. rubber hose (*c*) (Fig. 9) from the adaptor (*b*) on the delivery valve to the inlet of the inductor casing (*d*).

3. Connect the 1½-in. rubber hose (*e*) to the inductor outlet (*f*) and adaptor (*a*) on pump suction.

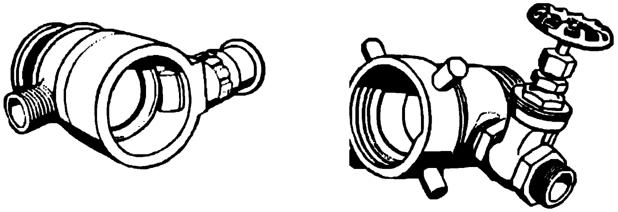


Fig. 8. Adaptors for coupling inductor to pump. Left : delivery adaptor. Right : suction adaptor.

4. When the inductor is connected up, fill the tank with foam compound.

5. Start and prime pump and run until 100 lbs. is shown on pressure gauge, then open the valves in the following sequence :—

(i) Delivery valve (*g*) connected by the adaptor and hose to the inlet on the multiple jet inductor.

(ii) Valve (*h*) on the pump suction adaptor.

(iii) As many inductor control cocks (*j*) as are required to supply the foam-making branches it is intended to use.

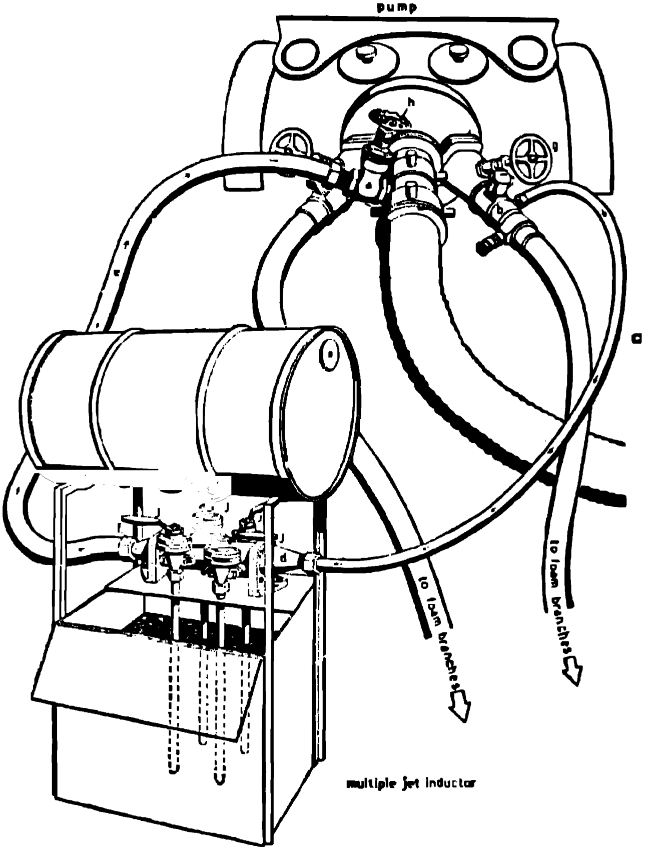


Fig. 9. Multiple jet inductor connected to pump.

It may sometimes be necessary to work from sources of water supply under pressure. Any back pressure on the inductor causes a falling off of the foam compound input, but this may be compensated for, even at 20 lbs. positive pressure, by using two No. 10's, with three control cocks open, or three No. 10's with four control cocks in use.

It may be desired to work off low-pressure mains which are at some pressure above 15 lbs. per sq. in. This can be done by only partially opening the hydrant valve until the vacuum gauge on the pump shows either a slight vacuum or a slight positive reading.

An alternative method of dealing with either low pressure or high pressure mains is to use portable dams. This is undoubtedly the most desirable method as involving no manipulation of valves, and should be used wherever the supply of dams makes it possible.

These dams are fed by hose from the pressure supply in the ordinary way, and the pump takes its water from the dam, so that a steady suction lift is obtained on the multiple jet inductor. This method is also applicable to cases where relay pumping is a necessity.

THE SUCTION FOAM INDUCTOR. This inductor differs from both the inline and multiple jet types in that the foam compound is drawn into the water stream by the vacuum which exists on the suction side of a pump when it is working from open water. It couples into the suction line and a short length of suction hose is provided to bring the inductor near to the pump.

The inductor (Fig. 10) consists of a 25-gallon tank (*a*) on which is mounted a short length of 4-in. diameter steel pipe (the suction tube) (*b*), fitted on the inlet side with a male 4-in. standard suction round-thread coupling (*c*) and on the outlet side with a female coupling (*d*). A large duct (*e*) feeds the foam compound from the tank through four separate pet-cocks (*f*) into the suction tube.

The bore of these cocks is such that when a 15-in. vacuum is maintained in the suction tube sufficient foam compound is drawn up each cock to feed one No. 10 foam branch. Upstream (*i.e.*, on the open water side) of these supply tubes is a sluice valve (*g*) which can be adjusted to maintain a 15-in. vacuum when the pump is at work. A vacuum gauge (*h*) on the pump side of the valve indicates the amount of vacuum. A detachable strainer (*j*) is fitted in the tank inlet below the supports (*k*) which hold the foam compound drums. A carrying handle (*l*) is provided at each side of the inductor to facilitate transport.

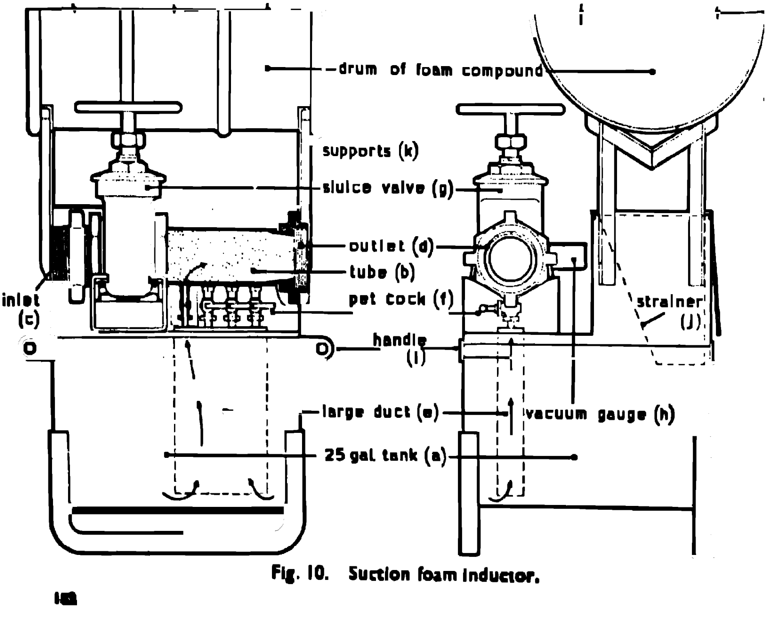


Fig. 10. Suction foam inductor.

Any increase in vacuum over 15 ins., as would automatically occur when working from lifts exceeding some 10 to 12 ft., merely results in a slight increase in the rate of induction of compound into the water stream and thus yields a slightly richer foam.

The whole piece of equipment is mounted on skids similar to those employed on the new type of inline inductor.

Instructions for operating the inductor are as follows :—

1. Couple the inductor in the suction hose line to the pump, using the 4-ft. length of suction hose between the pump and the inductor.
2. Make sure that the suction tube is not at a higher level than the pump inlet.
3. Fill the tank with foam compound and see that all four pet-cocks are closed. If it is desired to obtain an immediate discharge of foam from the branch, one of the cocks can be opened before priming so that compound is drawn into the suction tube to mix with the water rising to the pump.
4. Prime the pump in the usual way, after ensuring that the sluice valve is fully open (to prevent an air pocket behind the gate of the valve).
5. Open the pump delivery valve or valves. Then open the throttle to bring the pump pressure up to 100 lbs. per sq. in. and simultaneously close the sluice valve on the inductor until a reading of 15 in. shows on the inductor gauge.
6. Open one pet-cock for each No. 10 foam branch (or its equivalent) which is being supplied, *i.e.*, 2 cocks for a No. 20 and 3 for a No. 30 branch.
7. Further adjustment to the inductor during operations is necessary only when the pump settings are altered, *i.e.*, if the number of foam branches in use is increased or decreased.
8. In cases where the static lift is equal to or greater than that which will give a total suction when pumping of 15 in. (*i.e.*, about 12 ft. static lift) the sluice valve should be left fully open.
9. It is most desirable to work from open water whenever possible, and if a hydrant has to be used, the water should be allowed to discharge into a portable dam, if one is available, from which the pump can draw in the usual way.
10. The consistency of the foam can be varied at will. If a wetter foam is required decrease the vacuum reading on the inductor by slightly opening the sluice valve. To obtain a thicker foam open an additional cock, any further adjustments in the consistency being obtained as above. Do not operate the sluice valve to give a higher vacuum reading than 15 ins.
11. Exhaustion of the foam compound in the inductor tank will be immediately apparent as air will be drawn into the pump and consequently the gauges will fluctuate violently.

If it is impossible to avoid connecting the pump direct to a hydrant the inductor will operate satisfactorily provided the working pressure on the hydrant side of the valve does not exceed 25 lbs. per sq. in. At pressures above this figure it may be difficult to maintain a steady 15-in. vacuum reading, since the excessive throttling of the valve makes conditions unstable.

FOAM INLET ADAPTORS. In certain localities a proportion of No. 10 foam branches are modified in order that they may be used with foam inlets. The latter are more fully described in the Chapter on "Fixed Firefighting Installations (Part II)," but, briefly, consist of piping permanently fixed in position in certain buildings to convey foam from an inlet at street level to certain risks such as oil fuel tanks, etc.

In the foam branches so modified the cylindrical portion of the branch (the discharge tube) is joined to the rear tapered portion (the mixing tube) by a screw connection. When used in connection with foam inlets, the discharge tube is removed and a foam inlet adaptor (Fig. 11) is connected in its place. This adaptor is then connected to the foam inlet and the foam branch operated in the normal manner to force foam into the permanent pipe system.

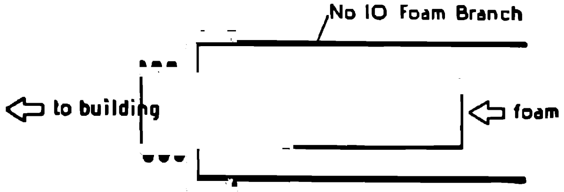


Fig. 11. Foam inlet adaptor.

(iv) *Larger Sizes of Foam-making Branch.* Whilst the No. 30 foam-making branch is the largest issued to the National Fire Service, there is practically no limit to the size of any single foam-making branch, provided sufficient water is available for operation. In general practice, however, where large-scale foam deliveries are required, it is better to have a number of the medium-sized branches rather than a few of large size.

(*b*) *Foam-making Pumps.* In another system mechanical foam is produced by means of a specially designed pump which performs the dual function of mixing the foam compound with water and air, and creating sufficient pressure to project it on to the fire. This pump may be either a fixed installation or mounted on a trailer chassis, an independent power unit being used in the latter case and either a power unit or an electric motor in the former. A few examples may also be found mounted on the rear of an appliance, and driven by a power take-off similar to that in the normal fire pump.

The pump employed in this system of foam production is of the fully rotary, positive displacement type (see the Chapter on "Pumps and Primers") and as with all pumps of this type a relief valve is employed to prevent excessive pressures being built up in the pump.

The foam compound is fed by gravity from a tank and water is taken in the normal way from any available source. Air is drawn in at the same time *via* a large air inlet mounted above the pump.

The mixture of foam compound, air and water is passed through the pump, where a partial formation of foam takes place, and is then driven at a pressure of about 45 lbs. through a mixing chamber which is so designed as to bring about a considerable fall in pressure. This reduction in pressure causes the air in the mixture to form masses of small bubbles giving a foam ready to apply to the fire. The final composition of the foam by volume is approximately 90 per cent. air, 9·7 per cent. water and 0·3 per cent. foam compound.

Two sizes of pumps are used. The first produces 300 g.p.m. of foam from 30 g.p.m. of water and the second 450 g.p.m. of foam from 45 g.p.m. of water. Some models can also be used in the normal way as a fire pump for water only.

Ordinary unlined canvas hose and standard branches can be used, and the amount of foam supply can be regulated by means of a control cock. The quality of foam produced can also be varied, but the proportions recommended by the makers are 1 gallon of compound to 30 gallons of water.

This type of foam-producing equipment is not normally used in the National Fire Service, but may be encountered at benzole producing and by-product plants and similar industrial undertakings. It may also be found at oil storage depots (usually in fixed installations discharging through special spreaders inside the tanks) and is sometimes used by gas companies to protect the tar seals in waterless gas holders.

PART I CHAPTER II

BREATHING APPARATUS

IT is well known that if respiration ceases, either from an insufficiency of oxygen in the atmosphere, or from some physical cause which makes breathing impossible (such as pressure on the throat or chest), then life cannot be maintained. It is equally well known that special apparatus can be used to support life in conditions under which it would otherwise be impossible for a human being to breathe. In order to understand fully the principles which govern the use of this apparatus, however, it is necessary to know something of the composition of the atmosphere and of the process of respiration itself.

Breathing or respiration is a spontaneous action which, unless some physical cause intervenes, is performed automatically by the human body some fifteen to thirty times every minute from the moment of its birth to its death. The body performs this action because it needs oxygen which is normally obtained only from the atmosphere. To obtain this, air must be drawn into the lungs, held for a sufficient time for the oxygen required to be absorbed, and then expelled. This process is known as respiration, and consists of two physical actions, inhalation (breathing in) and exhalation (breathing out).

Inhalation is caused by the enlargement of the chest cavity, by which air is drawn into the lungs, and exhalation by the contraction of the chest cavity, which expels the air from the lungs. Inhalation is effected by a muscular effort which raises the ribs and at the same time contracts the diaphragm, thus increasing the capacity of the chest and creating a partial vacuum which causes the air to enter. Exhalation requires no muscular effort, as, when the breath is released, the ribs fall and the diaphragm rises of their own volition, thus lessening the capacity of the chest and forcing the air out.

The atmosphere which is drawn into the lungs consists of three principal gases in the following proportions by volume :—

	Per cent.
Nitrogen (and rare gases)	79·04
Oxygen	20·93
Carbon dioxide	0·03

It also contains small percentages of five other gases, such as argon, etc., but as these constitute a total of about 0·91 per cent. of the atmosphere, and, moreover, can only be separated from nitrogen with difficulty, it is usual for ordinary purposes to include them in the percentage of nitrogen.

The three main gases, nitrogen, oxygen and carbon dioxide, are readily separated, as they are not combined with each other. Whenever the atmosphere is inhaled, therefore, nitrogen, oxygen and carbon dioxide are drawn into the body in these proportions.

The sustenance which the body requires from the atmosphere is derived from one of its constituents only, oxygen. Nitrogen takes no active part in respiration at ordinary pressures, being merely an inert gas which passes in and out of the body practically unchanged, whilst carbon dioxide, although it has a valuable function as a respiratory stimulant, is actually produced by the process of respiration in greater quantities than it is supplied by the atmosphere.

The function performed by oxygen in maintaining life is extremely complicated and is difficult to describe without using medical phraseology. To put it in the simplest form possible—the body may be likened to a great number of small chemical engines each of which needs fuel and oxygen to keep it running, and an exhaust to carry away the fumes. Every time a muscle is used, whether for walking, sleeping, eating, breathing, or other bodily function, one of these engines is started and fuel and oxygen must be supplied to it. The fuel is provided by the digestive system, and the oxygen by respiration. At the same time a quantity of carbon dioxide and other waste products is given off.

The transfer of the inhaled oxygen from the lungs to these engines, or in effect, to the muscles, is effected by the blood, which in its circuit of the body passes through the lungs, where it absorbs a certain quantity of oxygen. This oxygen travels with the blood through the main arteries to the lesser arteries, and finally into a vast network of blood vessels known as capillaries. These vessels have very thin walls through which a continual discharge of oxygen and assimilation of carbon dioxide takes place.

As was explained above, carbon dioxide and other waste products are given off in this process and these are absorbed into the blood through the capillaries, the oxygen carried by the blood being given off at the same time. The blood, which has now changed from a bright to a dark red, is then driven back by the action of the heart to the lungs where the carbon dioxide is given off (and exhaled) and a further supply of oxygen taken up.

In this process the composition of the air changes from :—

	Per cent.
Nitrogen	79·04
Oxygen	20·93
Carbon dioxide	0·03

to approximately :—

Nitrogen	79·04
Oxygen	16·96
Carbon dioxide	4·00

That is to say, about 4 per cent. of oxygen is absorbed and an equal amount of carbon dioxide given off. There is often a slight increase in the percentage of nitrogen, derived from the waste products of nitrogenous foodstuffs which are assimilated by the blood at the same time as the carbon dioxide.

The amount of oxygen required by the body to carry out these processes varies with the amount of work performed. If the body is resting, only the involuntary muscles governing the action of the lungs, the heart and the digestive organs are being used and consequently very little oxygen is required. As soon as the body becomes active, more muscles are used, a greater quantity of carbon dioxide is produced and a larger supply of oxygen is required.

Table I is compiled from a series of experiments undertaken by the late Professor J. S. Haldane, M.B., F.R.S., and gives an indication of the variation in oxygen consumption and air respired for varying degrees of exertion.

TABLE I

Degree of exertion	Oxygen consumed per minute in litres	Air breathed per minute in litres	Volume of air at each respiration	Number of respirations per minute
Rest in bed	0·237	7·7	0·457	16·8
Rest, standing . . .	0·328	10·4	0·612	17·1
Walking at 2 miles per hour .	0·780	18·6	1·27	14·7
Walking at 3 miles per hour .	1·065	24·8	1·53	16·2
Walking at 4 miles per hour .	1·595	37·3	2·06	18·2
Walking at 5 miles per hour .	2·543	60·9	3·14	19·5

Note.—28·3 litres = 1 cu. ft.

In heavier work, such as ascending an incline or running, the oxygen consumed may amount to 3 litres per minute, while the volume of air breathed may reach over 100 litres per minute.

From these data it is clear that in order to enable a man wearing breathing apparatus to walk along a level road at an ordinary speed of 3½ miles per hour, an oxygen supply of 2 litres per minute is needed to prevent risk of shortage of oxygen supply.

There are three fundamental facts which govern the efficiency of self-contained breathing apparatus :—

1. That not less than 2 litres per minute of oxygen, or a correspondingly greater volume of air, must be supplied for normal expenditure of effort.
2. The volume of carbon dioxide given off increases considerably with muscular exertion, and provision must be made for its effective removal. When a set is not of the closed circuit type, *i.e.*, when the exhaled air is expelled to the atmosphere, this provision is, of course, unnecessary.
3. The volume of air breathed increases rapidly with exertion above a normal amount, and provision must be made in the apparatus for an increased supply when required.

The function of breathing apparatus is to enable the wearer to work in an atmosphere which would not otherwise support life. The necessity of such an apparatus has long been appreciated, and primitive devices of various kinds were in use as long as a hundred years ago. The earliest types consisted of a muzzle fitting to the mouth with valves connected to which were tubes the ends of which remained in the outer air. This type was used for a considerable

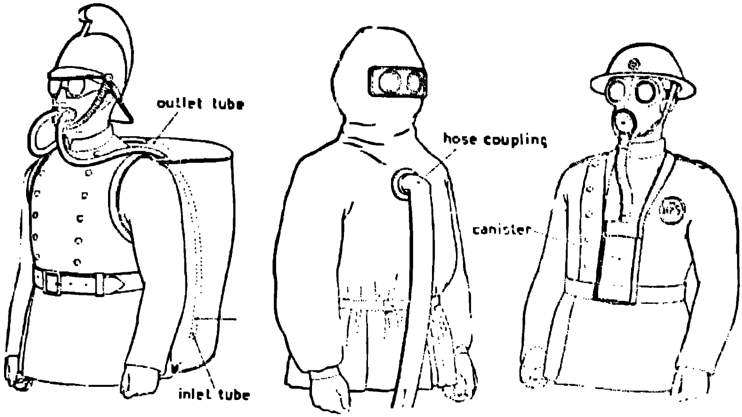


Fig. 1. Left: breathing bag. Centre: smoke jacket. Right: typical smoke respirator.

period, in default of anything better, but suffered from the disadvantage that the energy required to overcome the friction of the air passing through the pipe had to be provided by the respiratory efforts of the wearer and breathing was consequently extremely difficult. With improvements in the design of the face or mouthpiece and of the tubing, however, this type returned to favour.

A later development consisted of an air bag carried on the fireman's back, which enabled the wearer to enter a smoke-laden atmosphere and remain in it for two or three minutes by breathing and rebreathing the same atmosphere (Fig. 1, *left*). The intake was at the bottom where the air was cooler, the exhaled air being returned to the top.

A more complex apparatus consisted of an airtight helmet and jacket of cowhide fitted with a hose-coupling to which air, instead of water, was pumped from an appliance through the ordinary delivery hose (Fig. 1, *centre*). In this type the exhaled air escaped down under the skirt of the jacket and helped to keep the wearer cool in hot atmospheres. The defects of these two types are apparent.

A real attempt to master the problem was made in 1875 when Professor Tyndall, in conjunction with Sir Eyre Massey Shaw, devised and introduced a "smoke cap," which was in fact the first respirator. This was similar in essentials to modern respirators, consisting of an airtight hood into which air was drawn from the atmosphere *via* a canister containing filtering elements.

All the earlier types of breathing apparatus were dependent upon a supply of oxygen from the atmosphere for their success. It was originally thought, from an insufficient understanding of the principles of respiration, that a respirator which would filter smoke and other gases would be effective under all conditions.

It was not realised that the greatest danger at a fire was due to oxygen deficiency, which nothing but a supplementary supply of air or oxygen could remedy. At least 16 per cent. of oxygen is necessary to support life, and where, due to combustion, the percentage in the air is reduced below this figure only apparatus which will provide its own supply of air (or oxygen) will enable the wearer to continue at work.

Apparatus depending on a self-contained supply of oxygen was produced for use in mines as early as 1881, but this type of breathing apparatus was not widely adopted for Fire Service use until after the first world war. The superiority of the self-contained apparatus is now generally recognised, and the greater part of this chapter will therefore be devoted to sets of this type.

The breathing apparatus used by the Fire Service to-day falls into two main categories :—

The atmospheric type, by which atmospheric air is furnished to the wearer by his own or another's effort.

The self-contained type, by which air or oxygen in highly compressed form is furnished to the wearer from an independent supply carried on the apparatus.

In some sets, used to a limited extent in mines, the oxygen is carried in liquid form and evaporated as required.

These two main categories can be further subdivided as follows :—

ATMOSPHERIC TYPES

1. Respirator or air-filter type masks.
2. Equaliser tube apparatus.
3. Bellows type smoke helmets.

SELF-CONTAINED TYPES

1. Peroxide type respirators.
2. Open circuit self-contained types, in which the exhaled air is discharged into the atmosphere.
3. Closed circuit self-contained types, in which the exhaled air is returned to a breathing bag, regenerated, and used again.

ATMOSPHERIC TYPE BREATHING APPARATUS

I. RESPIRATOR OR AIR-FILTER TYPE

This class of apparatus, generally known as a " smoke mask," is rapidly becoming obsolete for Fire Service use, as it can only be employed with safety in atmospheres containing not less than 16 per cent. of oxygen. All this type of apparatus derives from the first respirator produced by Professor Tyndall, the principle of air filtration being common to all. The apparatus consists essentially of a mouthpiece or facepiece to which air is supplied by a breathing tube from a canister containing charcoal, lime, glycerine or other substance. A typical smoke respirator is shown in Fig. 1 (*right*). Considerable variation is found in the elements used in the filter, and in the type of mask, which may consist of anything from an elementary mouthpiece and nose-clip to a complete hood.

The general service and civilian duty respirators fall into this category, but are, of course, designed for use in the open air, and against gases which are unlikely to be encountered in large concentrations.

The canisters with which they are fitted are designed to give protection against both true gases and the "particulate" war gases which are not true gases but consist of solids in an extremely fine state of division.

The filter which gives protection against the "particulates" consists of a wad of very fine absorbent material to the fibres of which the fine particles of particulate adhere. For this reason these respirators should never be used as a protection against smoke, since the particles of which smoke is composed are very much larger than those of a particulate war gas and would clog the absorbent filter. Moreover, if the respirator is used for a short time only the effect might not become apparent, but the canister might none the less prove ineffective if used at a later date in a concentration of particulate gas.

2. EQUALISER TUBE APPARATUS

This is an apparatus by which the wearer draws a supply of air from the atmosphere by his own effort. It is designed for work at a short distance from fresh air only. A typical apparatus (Fig. 2, *left*) comprises a facepiece, with non-return outlet valve for the passage of the exhaled air and a flexible corrugated tube of rubber covered externally with elastic fabric and connected to the base of the facepiece to which is fitted a non-return inlet valve. This tube passes down in front of the body and is connected to an adaptor fixed on a leather belt strapped around the waist of the wearer. A length of

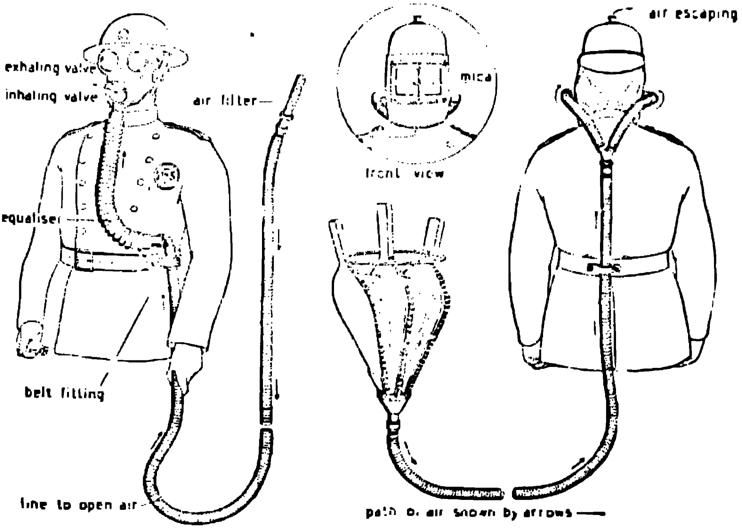


Fig. 2. Left: equaliser type breathing apparatus. Right: bellows type smoke helmet.

strong wire-embedded air pipe, the bore of which is smooth in order to reduce resistance to inhalation, is connected to this adaptor. The free end of this tube, which is usually 60 ft. long, but may be 120 ft., is secured in fresh air, a strainer being fitted to prevent the ingress of foreign matter. A mouthpiece fitted with the appropriate valves is often preferred as giving a more direct and positive suction effect on inhalation.

From the illustration (Fig. 2, *left*), it can be seen that the operator requires no assistance when working in this apparatus, but it is of paramount importance that the free end of the pipeline is in pure air and a man should always be left in attendance at the free end to ensure that it is not tampered with, or moved into an impure atmosphere.

ADVANTAGES :

(*a*) Cheapness in first cost, and no maintenance costs.
(*b*) Comparatively light in weight.
(*c*) No air valves to manipulate.
(*d*) No limit of time in which to operate.

DISADVANTAGES :

(*a*) The air tubing has to be trailed behind the wearer thus restricting his movements to a certain extent and limiting the distance to which he can travel.

(*b*) The air tube may be cut or damaged by falling debris or other causes.

(*c*) The supply of air is dependent on the respiratory efforts of the wearer and may involve considerable exertion.

3. BELLOWS TYPE SMOKE HELMETS

There are various types of smoke helmets in use in the Fire Service but all are similar in principle and operation. A popular type consists of a simple headgear blocked out of hide which fits over the head of the wearer, hood fashion, and has an arrangement inside the crown by which the helmet can be adjusted to fit all sizes of heads. A piece of soft leather attached to the base of the helmet which is tucked in under the wearer's tunic or coat, effectually seals the lower part of the helmet from surrounding air. In the front are fitted small clear mica windows in aluminium-hinged frames which give a wide field of vision and are made so that they can be instantly opened and closed with a special locking device (Fig. 2, *right*). Air enters the helmet by means of breathing tubes at each side of the helmet which pass back over the shoulders of the wearer and are connected to the air pipeline. The pipeline then passes through a metal clip attached to a belt that is worn around the waist of the wearer. This clip firmly fixes the pipeline, so that any strain on the line is taken by the belt, to prevent the helmet being dragged out of position. An exhaling valve is fitted on top of the helmet to allow the escape of excess and vitiated air.

The air pipeline is non-collapsible, having embedded wire or armouring, and metal couplings. It is connected to a set of bellows which can be of pedal, hand, or sometimes power operated type ; this is situated in pure air and with the efforts of a second person supplies a continuous flow of fresh air to the wearer of the apparatus. This apparatus has been used extensively for dealing with fires on board ships and has proved to be satisfactory in working in noxious atmospheres, but is, however, being superseded by the self-contained breathing set for Fire Service use.

ADVANTAGES :

(*a*) It is cheaper than self-contained apparatus and there are no maintenance costs.

(*b*) There is a minimum possibility of mechanical defects.

(*c*) The wearer has no valves to manipulate and no dead weight to carry on the body.

(*d*) There is no limit to the supply of air and the apparatus can therefore be worn for prolonged periods.

(*e*) Owing to the complete covering of the face and head these are protected from dangerous fumes such as those of ammonia which might burn the skin.

(*f*) In hot atmospheres the constant supply of cool air gives protection to the wearer against heat stroke.

(*g*) The wearer can find his way out of the building by following the tubing.

DISADVANTAGES :

(*a*) The constant supply of air is always dependent upon a second person.

(*b*) The air tubing has to be trailed behind the wearer thus restricting his movements to a certain extent and limiting the distance to which he can travel.

(*c*) The air tube may be cut or damaged by falling debris or other causes.

(*d*) The apparatus as a whole is somewhat bulky to stow.

SELF-CONTAINED BREATHING APPARATUS

I. PEROXIDE TYPE

This type of apparatus has not been widely developed, but a few sets are in use in the Service and mention should therefore be made of it here. It consists of a normal respirator-type facepiece, breathing tube and canister. This canister, however, instead of containing charcoal or other filtering agent is filled with chemicals (the peroxides of sodium and potassium) which evolve oxygen and absorb carbon dioxide when breathed upon. The effect is therefore to give a partially self-contained character to the mask.

There are, however, disadvantages to this type of set which have not yet been overcome, and which render its use impracticable for sustained firefighting work. These are :—

(*a*) That respiration is extremely difficult.

(*b*) Owing to the fact that the reaction of the peroxides is exothermic, considerable heat is produced, which renders the set uncomfortable, and in some circumstances even dangerous, to the wearer.

(*c*) The peroxides do not react immediately, so that some minutes elapse before oxygen is evolved in sufficient quantity to support life. The wearer is therefore in danger of being asphyxiated if he attempts to work immediately after donning the apparatus.

2. OPEN CIRCUIT SELF-CONTAINED TYPE

This category comprises all types of breathing apparatus in which a supply of oxygen or compressed air is fed to the wearer from cylinders or other containers and expelled into the atmosphere. This type of set is known as the " open circuit " type, to distinguish it from other types, to be described later, in which the air is returned into a breathing bag, and regenerated by means of chemicals instead of being exhaled. There is no regenerative action necessary with the open circuit type of apparatus, since the carbon dioxide in the exhaled air is expelled into the atmosphere.

There are two principal types of compressed-air breathing apparatus sets in use in this country. One of these is of foreign manufacture, and was the original set of its type, the other being an English apparatus. The latter is, however, described first as it is the one more widely used in the Fire Service.

(*a*) *Compressed-air Breathing Apparatus.* (Type One). This consists of a facepiece, a lung-controlled respiratory system, and a harness on which are carried an interchangeable pair of air cylinders (Fig. 3).

The facepiece is similar to that of the general service type respirator. It is made from moulded rubber reinforced by a stockinette covering. The lenses, which are removable, are of splinter-proof safety glass, and misting is reduced, as in the service facepiece,

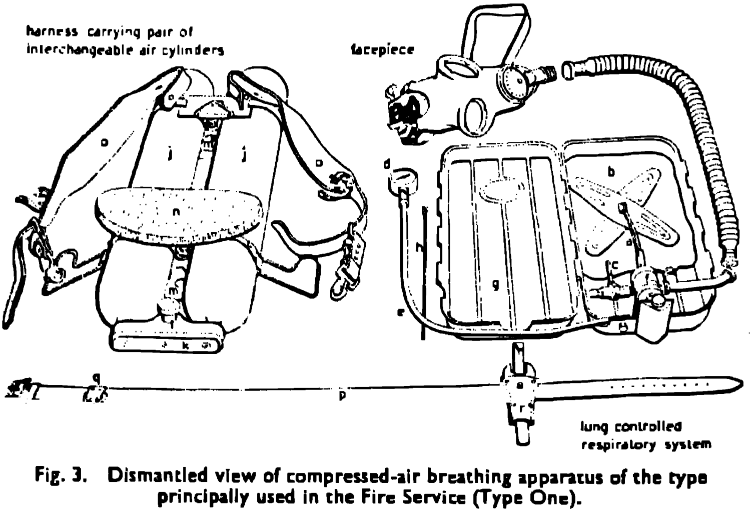

harness carrying pair of interchangeable air cylinders
facepiece
lung controlled respiratory system
o
o
j
j
o
n
k
q
p
d
b
h
a
c
g
e

Fig. 3. Dismantled view of compressed-air breathing apparatus of the type principally used in the Fire Service (Type One).

by the cool inhaled air being deflected across the inner surfaces of the lenses through a channel moulded into the facepiece. The exhalation valve is controlled by a spring which maintains a slight positive pressure inside the facepiece.

The lung-controlled respiratory system consists of a composite rubber diaphragm reducing valve, controlled by a lever (*a*) ; a breathing bag (*b*) ; a warning whistle (*c*) , a pressure gauge (*d*), with flexible tube (*e*). The action of these parts in controlling the supply of air to the facepiece is clearly shown diagrammatically in Fig. 4. The air flows from the cylinders through the reducing valve (*f*) and into the breathing bag. The rise and fall of this bag (which is governed by the rate of breathing) raises or depresses the lever (*a*) and so closes and opens the reducing valve which regulates the amount of air passed in accordance with the requirements of the wearer. The amount of this automatic supply is determined by a governing screw on the lever, which determines at what point in the travel of the lever the reducing valve opens or closes.

The reduction in the pressure of the air from the high pressure in the cylinder to a breathable pressure is brought about by the action of the lever in opening and shutting the valve.

When the control valve is first opened a quantity of air flows from the cylinder into the breathing bag. This air, although it leaves the cylinder at a high pressure, will not retain this pressure in the breathing bag since it has there a comparatively large space in which to expand. If air was allowed to go on entering the bag the pressure would gradually increase until eventually the bag burst. Before a sufficient quantity of air enters the bag to build up such a pressure, however, the distension of the bag raises the lever and so closes the reducing valve.

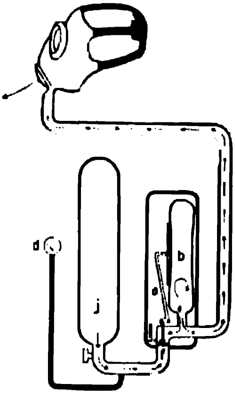


Fig. 4. Simplified diagram showing air circuit of open circuit compressed-air breathing apparatus.

When the wearer takes a breath the bag collapses and the lever falls, thus opening the reducing valve and allowing more air to enter the bag. The reducing valve is thus continually opening and closing for as long as the bag is in use.

The complete respiratory system is contained in a hinged metal casing (*g*), which is easily opened for inspection by withdrawing the loop-ended pin (*h*) at the side of the casing.

The air cylinders (*j*) are of seamless manganese steel, each having a water capacity of 4 litres, and are inter-connected by means of a bridge-piece (*k*) fitted in the middle with a common control valve (*l*) governing the flow of air. Each cylinder is tested to withstand a pressure of 3,000 lbs. per sq. in. and the bursting pressure is in the neighbourhood of 5,800 lbs. per sq. in. The two cylinders are joined by metal braces (*m*), the lower one being fitted with a soft rubber sponge pad (*n*) to form a back rest.

In use, the cylinders are normally charged with air compressed to 120 atmospheres (1,800 lbs. per sq. in.) equivalent to 954 litres of free air, or a supply sufficient for between 20 and 30 minutes under working conditions equivalent to walking at 4 m.p.h.

It is now permissible to increase the pressure in manganese steel air cylinders to 150 atmospheres (2,250 lbs. per sq. in.) and this will increase the time from 20 to 30 minutes to 24 to 36 minutes assuming the same conditions.

The cylinders and respiratory system are carried on the wearer's back by means of a leather harness, comprising two shoulder straps (*o*) and belt (*p*), which is fitted with a " D " ring for a lifeline (*q*) and a pouch (*r*) to carry the spanner which is required for tightening up the cylinders to the respiratory system.

The complete apparatus weighs 44½ lbs.

Assembly. The apparatus is assembled as follows:—

(i) Lay the cylinders on a table or other support, with the harness downwards. Insert the tongue on the top of the casing into the slot on the upper cylinder brace, keeping the nameplate on the casing upwards. Couple up the union on the bottom of the casing to the milled union of the cylinder bridgepiece and tighten firmly with the spanner. Connect the corrugated tube on to the air outlet of the casing, making sure that the rubber washers are in place, and tighten sufficiently to make an airtight joint. It is immaterial which end of the tube is connected to the outlet as both are identical.

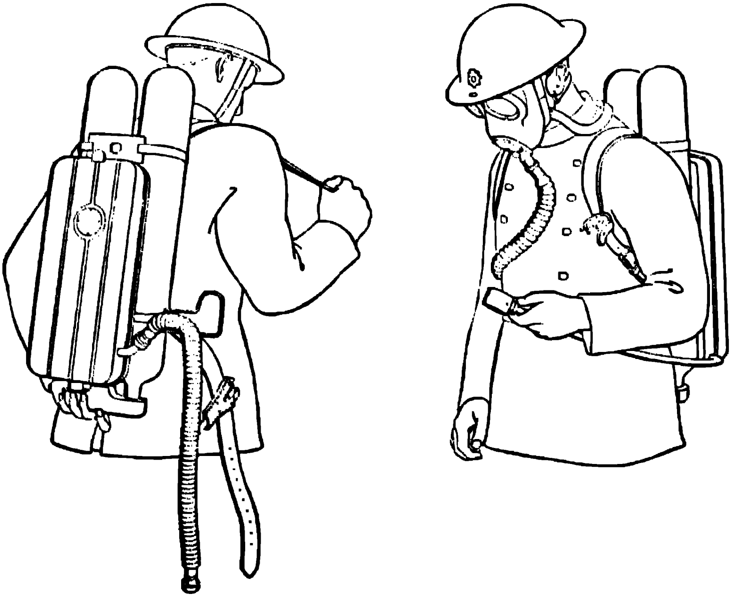


Fig. 5. Open circuit breathing apparatus (Type One). Left: back view. Right: front view.

Before proceeding further, the assembly should be tested for air-tightness. To do this, hold a thumb firmly over the free end of the breathing tube and open the cylinder valve slowly (not more than half a turn). The air will be heard entering the respiratory system, and a reading of the pressure gauge should be taken to ascertain the amount of air in the cylinders. Any escape of air from the cylinder union will be heard immediately, and should be rectified by tightening the joint. The valve should then be shut, and the thumb lifted, when the air will escape from the respiratory system *via* the tube. The pressure gauge should be watched as the air is escaping to make sure that the whistle sounds as the needle passes the 300 lbs. mark.

(ii) Slip head through the tape sling on the facepiece ; put on the facepiece and test it for air-tightness by closing the screw union with the thumb and inhaling. The facepiece should then be taken off and left hanging from the sling in the " Alert " position.

(iii) Attach the pressure gauge to the left shoulder strap, and hook the strap on to the cylinder-carrying arm, leaving the right strap free. Stand the set upright on the edge of a table or other support and put on like a pack, by inserting the left arm through the shoulder strap and then securing the right shoulder strap to its carrying arm (Fig. 5, *left*).

(iv) Secure the belt and attach breathing tube to the facepiece, making sure that it is in a straight line so that the tube is not twisted.

(v) Put on facepiece and at once open cylinder valve slowly by reaching back with the right hand. Before entering a toxic atmosphere a pressure gauge reading should be taken (Fig. 5, *right*) to ascertain how much air is available. Since the set is lung operated, the length of time which the cylinders will last is dependent on the depth and rate of respiration of the wearer. Provided fully charged cylinders are employed, protection should be obtained for between 20 and 30 minutes.

The amount of air remaining in the cylinders at any time can be ascertained by taking a pressure gauge reading. This gauge is calibrated in lbs. per sq. in. and in atmospheres. In addition a red line is inscribed at 1,800 lbs. to indicate that the cylinders are full ; a blue line at 1,100 lbs. to indicate half-full ; and a black line at 300 lbs. as a warning that the supply is running low. The position of the pressure gauge needle in relation to these lines gives an immediate indication of the amount of air remaining in the cylinders.

An additional warning to the wearer that the supply is running low is given by the whistle incorporated in the respiratory system, which is set to sound as the pressure gauge needle reaches the 300 lbs. mark. Under normal working conditions approximately five minutes supply of air is available when the whistle sounds.

Changing Cylinders. When the cylinders are exhausted they can be changed very simply as follows :—

(i) Remove set and lay on table or ground. Unscrew milled union nut and remove respiratory system.

(ii) Attach fresh cylinders to respiratory system, by screwing up milled union nut.

(iii) Uncouple harness from old cylinders and assemble as before.

The cylinders can also be changed in an emergency in a toxic atmosphere without interruption of protection but this is not recommended as a general practice. To effect this :—

Unsling harness and lay cylinders on the ground with the respiratory system upwards (by assuming a kneeling position it is quite easy to do this without removing the facepiece) ; remove the blank cap on the two way union and attach a pair of charged cylinders as described above. The valve on the fresh cylinder can now be opened, when the higher pressure which they contain will immediately push over a sliding valve in the union and shut off the spent cylinders. The spent cylinders can now be removed and the blank cap replaced on the screw union.

When the set is put on again it will be found that the positions of the breathing tube and the pressure gauge have become reversed, the latter now coming in the right shoulder strap instead of the left. A clip is fitted on both right and left shoulder straps to accommodate the gauge in either position.

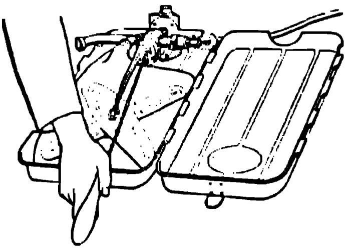


Fig. 6. Use of adjusting screw for regulating the air supply on open circuit compressed-air breathing apparatus.

Regulation of Air Supply. The reducing valve and lever are set by the makers to give an air supply sufficient for normal exertion. An increased supply can be obtained if it is known that the set is to be worn under exceptionally arduous conditions, by means of a governing screw on the lever (Fig. 6). To increase the amount of air delivered the screw should be turned in a clockwise direction. A quarter of a turn will usually be found to give sufficient variation. There is a small lock nut beneath the governing screw which must be slacked off to effect this adjustment. When a satisfactory supply has been achieved this lock nut should be carefully tightened, holding the governing screw with a screwdriver at the same time to prevent the adjustment being disturbed.

Warning Whistle. The warning whistle is set by the makers to sound when the pressure falls to approximately 300 lbs., which should give a further five-minute supply under normal working conditions. If considerable energy is being expended, the remaining supply will inevitably last for a shorter period, and it may be desirable in such circumstances to alter the setting so that the whistle sounds at a higher pressure.

To effect this adjustment, remove the slotted cap on the end of the whistle block, beneath which will be found an adjusting screw. To increase the pressure at which the whistle sounds the screw should be turned in a clockwise direction. The effectiveness of the adjustment can be tested by turning on the cylinder valve for a moment and then shutting off. The whistle will sound as the pressure gauge needle passes the new setting.

Reducing Valve. The setting of the reducing valve is extremely delicate and no attempt should be made to interfere with it. If any defects arise the valve should be returned to the makers for readjustment.

Recharging Cylinder. Empty cylinders can be recharged by the suppliers of the set, or by means of a suitable three-stage compressor which can be operated by Fire Service personnel with the necessary training. An empty cylinder can be charged in about ten minutes by such a small portable compressor. It is important that compressors used for charging cylinders should be fitted with an air filter and a moisture and oil separator to ensure that only clean, dry air is charged into the cylinder. Air intakes on stationary compressors should be led in from outside the charging room at a height which will ensure that the air drawn in is not contaminated in any way. It is important that the air compressor shall be kept in first-class running order and that under no circumstances is it allowed to overheat. Under such conditions dangerous quantities of CO might be produced by the decomposition of the lubricating oil and these would be compressed into the cylinders and might poison the wearer.

(b) Compressed-air Breathing Apparatus (Type Two). This type of compressed-air breathing apparatus (which is of foreign manufacture) is similar in essentials to the first set described above, detail differences only characterising the two types.

The set comprises a similar lung-controlled respiratory system, interchangeable cylinders and respirator type facepiece, the operation and maintenance of which are identical with those described above. The following slight differences should, however, be noted :—

(i) The facepiece is of a different pattern, being constructed of moulded rubber, and having no stockinette covering. The lenses are of mica, and although removable, are of a different type, being secured by a steel ring held in position by a small nut and bolt. The breathing tube is also of uncovered corrugated rubber, and is permanently secured to the respiratory system, the facepiece end only being removable.

(ii) The respiratory system is similar in operation and construction, but the whole system is reversed, the reducing valve and breathing tube being on top instead ot on the bottom. The aluminium casing is also in two pieces, joined by four nuts and bolts and not hinged.

(iii) The cylinders are of lighter construction than those used with the type previously described and the charging pressure specified by the makers is 3,000 lbs. per sq. in. Such pressures do not comply with the Home Office Statutory Rules and Orders, and would not be permissible in Great Britain. The cylinders of this type, when used in Great Britain, must therefore be charged to the pressures specified above for the previous type.

Owing to the lighter construction of the cylinders the set weighs less than the first type, namely 27 lbs., and due to the higher charging pressure gives a longer supply. The position of the main air control valve (in the middle of the shoulder blades) is awkward and a person with short arms may find difficulty in reaching it. Also, the construction of the respiratory chamber casing makes rapid inspection impossible as it has to be dismantled before the cover can be removed.

(c) *Other Compressed-air Breathing Apparatus.* Sets of breathing apparatus employing compressed air are also made with no respiratory chamber or breathing bag, the amount of air supplied to the wearer being regulated by means of a fine thread screw valve on the cylinder. This valve serves the double purpose of main control and reducer.

Sets of this type can, however, only be regarded as emergency short-term apparatus, as they carry a supply of air sufficient for a maximum of about 15 minutes of normal exertion only.

The advantages of the compressed-air type of apparatus described in (a) and (b) above are :—

(i) Having an independent supply of air the wearer can move about freely, unrestricted by breathing tubes or by doubts as to the efficiency of the canister against the particular atmospheric conditions in which he is working.

(ii) It is extremely simple in assembly and operation and relatively little training is required for men to become proficient in its use.

(iii) Spent cylinders can be changed very simply and quickly (if necessary in a toxic atmosphere without interruption of supply) and there are no chemicals to discard and replace after use. The whole apparatus can be made ready again for use in one minute.

(iv) The cylinders themselves are easily recharged. Small portable compressors can be employed to charge the cylinders locally. This obviates the necessity for sending cylinders away and thus effects considerable economy in the need for maintaining large stocks of spare cylinders.

(v) As no chemical action is involved the air breathed tends to remain cooler, even when working in a heated atmosphere.

(vi) The use of a respirator-type facepiece frequently enables men working together to convey information by word of mouth instead of by signals, which is not only more convenient but gives increased confidence.

The disadvantages are :—

(i) Owing to the fact that the supply is lung-controlled and is exhaled to the atmosphere the duration varies within wide limits. The set is therefore only suitable for short periods since it cannot be relied upon for an extended time, even though the supply may be sufficient if little effort is expended.

(ii) The apparatus is heavy (44½ lbs.) and as the whole of the weight is carried on the back, pack fashion, tends to drag on the shoulders and makes it difficult for the wearer to carry an injured or insensible person on his back.

(iii) The apparatus is not sufficiently flexible. The cylinders, being rigid, make bending difficult and in some types the control valve is difficult to reach.

(iv) The respirator-type facepiece (essential with open circuit apparatus) is not regarded as so convenient for Fire Service work as a mouthpiece. Respirator-type facepieces need adjustment for different faces, and the same size will not fit everyone.

3. CLOSED CIRCUIT SELF-CONTAINED BREATHING APPARATUS (WITH REGENERATIVE ACTION)

This category comprises all those types of breathing apparatus in which the exhaled air is returned to a breathing bag and inhaled again after it has been purified by filtering through a carbon dioxide absorbent medium and the oxygen has been replaced.

The principal difference between this type and the open circuit types described is that the supply of oxygen for regeneration purposes can be regulated to a given amount per minute, irrespective of the energy expended, and the duration of the supply is therefore predetermined.

In sets of the closed circuit type, therefore, the working time can be predetermined within exact limits, and provided a suitable by-pass is incorporated to make good any temporary shortage of oxygen due to sudden great exertion, these sets are to be preferred for any other than short period working.

If the supply of oxygen or air is to be regulated so that a given amount flows per minute irrespective of the energy consumed, then a breathing bag or other container must be provided in which a reserve of air can be built up, and the exhaled air must be returned to this reserve. Since the exhaled air will contain a percentage of carbon dioxide it follows that a means must also be provided for absorbing this gas so that the air is purified before being re-inhaled. Sets employing a circuit of this sort are known as the closed circuit regenerative type.

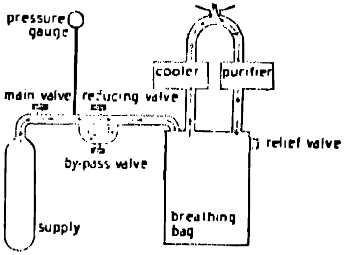


Fig. 7. Diagrammatic sketch of layout of closed circuit regenerative apparatus.

The air circuit employed by this type of apparatus is shown in diagrammatic form in Fig. 7. A cooler is not an essential feature, but is a desirable addition as a certain amount of heat is generated in the circuit. This circuit from the breathing bag to the mouthpiece and back in an endless circle is common to all types of regenerative apparatus. When liquid air is employed instead of oxygen, however, there is a slight difference on the supply side of the circuit.

Oxygen is stored in cylinders charged at high pressure, which has to be reduced before the oxygen can safely be fed into the breathing circuit. A reducing valve is an essential feature of all breathing apparatus employing compressed gases.

Liquid air, on the other hand, is carried in special containers called "packs" built up of material which absorbs the liquid air in the

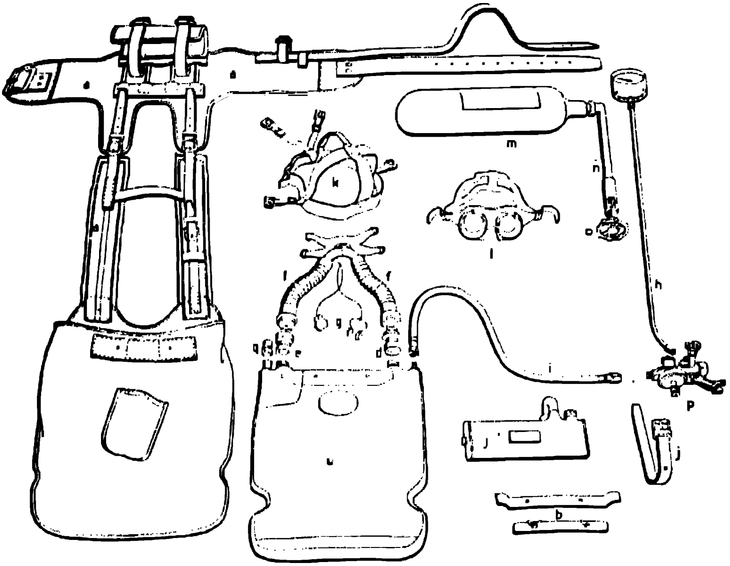


Fig. 8. Dismantled view of "Proto" one-hour closed circuit regenerative breathing apparatus.

same way as a sponge absorbs water. These packs contain 5½ lbs. in weight of liquid, producing 2,000 litres of air, which boils off at atmospheric pressure. No reducing valve is necessary with this type of apparatus, since the air can be fed direct into the breathing circuit. Liquid air sets are not used by the Fire Service but are employed in mines rescue work owing to the length of time (up to three hours) for which they can be worn.

(a) **Proto.** The regenerative breathing apparatus most commonly employed for Fire Service work is the "Proto" one-hour oxygen breathing apparatus. A dismantled view of this apparatus is shown in Fig. 8.

The set comprises (*a*) a canvas harness, (*b*) breathing bag clamps, (*c*) breathing bag, (*d*) inhalation valve, (*e*) exhalation valve. (*f*) breathing tubes and mouthpiece, (*g*) noseclip and mouthpiece plug, (*h*) pressure gauge and tube, (*i*) supply tube, (*j*) cooler and securing strap, (*k*) skull cap and (*l*) goggles, (*m*) oxygen cylinder with (*n*) anti-rust tube and (*o*) main valve, (*p*) valve group, and (*q*) relief valve.

The oxygen cylinder contains 6 cu. ft. of oxygen compressed to 120 atmospheres (about 1,800 lbs. per sq. in.) and is fitted with a main valve having a safety locking bolt. The cylinder is connected by means of a screwed union nut and fibre washer to the valve group, a diagrammatic arrangement of which is shown in Fig. 9.

When the main valve is opened the oxygen (at high pressure) passes up through a channel in the central column to a small jet at right angles to the column, from which it is fed into a chamber known as the floating valve chamber.

The purpose of this floating valve is to reduce the high pressure of the oxygen in the cylinder to a breathable pressure. The oxygen is fed from the central column (*a*) into a chamber (*b*), the only outlet from which is by a small orifice (*c*) in the back pressure disc. At the opposite side of the chamber is a diaphragm (*d*) having a slight margin of lateral movement which is controlled by a strong spiral spring (*e*). Connected to this diaphragm is a fibre valve (*f*) which controls the supply of oxygen from the jet (*g*). When the spring is released the jet is open, but as soon as the spring is compressed the fibre valve (*f*) is drawn down by the diaphragm and closes the jet.

So long as the oxygen is turned off the fibre valve is held away from the jet by the spiral spring acting on the diaphragm. As soon as the main valve (*h*) is opened, however, oxygen at high pressure begins to fill the chamber (*b*) and as only a small quantity can escape through the orifice (*c*) in the back pressure disc, a considerable pressure is built up. This pressure, exerted on the large area of the diaphragm, forces it over against the spring, at the same time moving the fibre valve (*f*) and closing the jet. The oxygen then continues to escape slowly *via* the orifice in the back pressure disc (*c*) until the pressure in the chamber is sufficiently reduced for the spring to overcome it, force the diaphragm and fibre valve back, and so allow more oxygen to enter.

The exact amount of oxygen passing the reducing valve can be regulated by adjusting the pressure on the spiral spring (*e*) by means

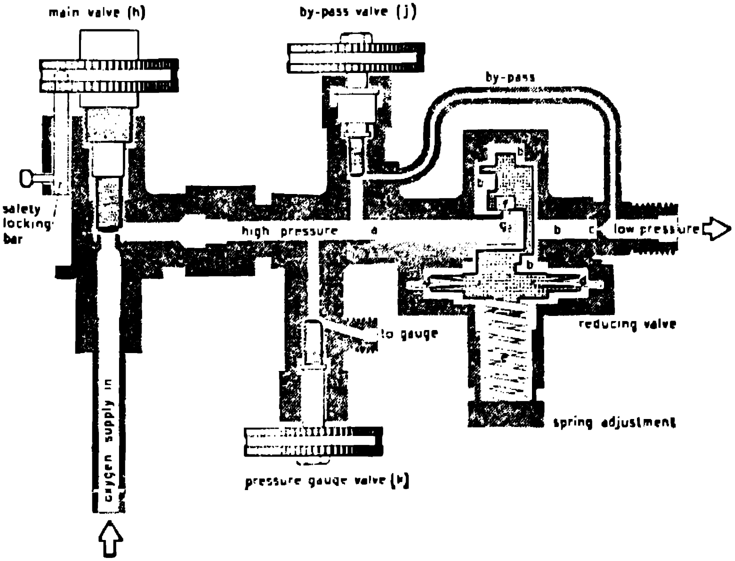


Fig. 9. Diagrammatic arrangement of " Proto " valve group and main valve.

of an adjusting sleeve, compressing the spring giving a greater supply, and *vice versa*.

This lateral movement of the diaphragm and fibre valve is independent of pressure in the cylinder and continues until the supply of oxygen is exhausted. The movement is so rapid that a slight buzzing sound is sometimes set up by the vibration of the moving parts. (This can be stopped by a light tap with a spanner on the blank cap of the floating valve.)

A by-pass valve (*j*) and pressure gauge valve (*k*) are also included in the valve group. The function of the by-pass valve is to enable the wearer to supply himself with additional oxygen direct from the cylinder. The reducing valve is set to give a regular supply of 2¼ litres per minute irrespective of the pressure in the cylinder or the amount of oxygen consumed by the wearer. This supply is sufficient for all normal purposes, but may need to be supplemented slightly if exceptionally strenuous work is being undertaken by the wearer. By opening the by-pass valve an immediate supply of oxygen can be obtained to satisfy the wearer's requirements, the oxygen entering the system on the low pressure side of the reducing valve through perforations in a screw plug just beyond the back pressure disc. The by-pass may also be used to flush out the bag with cool oxygen if the temperature has risen to an uncomfortable degree.

A pressure gauge valve is fitted to enable the wearer to shut off the oxygen should the gauge or its flexible cable become damaged. In normal use the valve is left open, and therefore requires no attention when wearing the apparatus.

From the valve group the oxygen is fed *via* a flexible supply tube into the left-hand side of the breathing bag (*i.e.*, on the wearer's left). The bag is made from strong vulcanised indiarubber, and is carried in an outer bag of waterproof canvas in which it is secured by steel clamps bolted back and front. The breathing bag is divided into two compartments which communicate at the bottom, and is fitted at the top right-hand corner with a relief valve by means of which any excess of gas which has accumulated in the bag can be released.

The communicating compartment at the bottom of the bag is filled with a carbon dioxide absorbent which is usually in granular form, although caustic soda is sometimes used. To prevent the absorbent being disturbed and blown about the bag by the blast of oxygen which occurs when the by-pass valve is momentarily opened, a diffuser is secured to the oxygen inlet connection to break up the flow. This diffuser consists of a hollow metal sphere, the lower half of which is perforated circumferentially to allow the passage of oxygen. It can be removed very simply, and should be examined periodically to ensure that the perforations are always kept clear.

There are three different types of absorbent in use with these sets:—

(i) Caustic soda stick.
(ii) Coke absorbent.
(iii) A proprietary mixture consisting of a white granular substance.

(i) Caustic soda sticks in use assume a brown sticky state which is difficult to remove from the bag. It is therefore necessary for the bag to be washed out with warm water when the absorbent is removed. The bag must be thoroughly dried before being recharged with absorbent.

(ii) Coke absorbent also tends to become sticky after use (though not to the same extent as the caustic soda stick) and the breathing bag must be washed out when it is being removed. It is also inclined to be dusty and cases have been known when men, owing to working in a prone position or crawling, have drawn a certain amount of dust into their mouths. Although unpleasant it is not injurious.

(iii) The proprietary absorbent consists of a white granular substance which, to the naked eye, presents the same appearance after use as when first put into the breathing bag. As it remains dry and does not powder appreciably when in use, it is not necessary to wash out the bag every time. The usual procedure is to dust out the bag with a dry cloth and occasionally with a damp cloth.

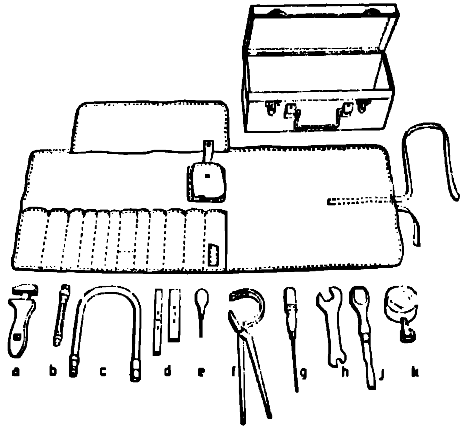


Fig. 10. "Proto" tool kit.

Types (i) and (ii) require a different pattern bag from that used with type (iii). Sets which have previously used coke absorbent will therefore have to be fitted with bags suitable for use with granular absorbent when existing stocks of the former become exhausted.

Beside the relief valve, on the right-hand corner of the bag is a connection for the exhalation valve and breathing tube, and in a similar position on the left-hand corner, a connection to which is secured the cooler. The mouth of the bag is sealed by the brass clamps which hold the bag in position in the outer canvas container.

The cooler consists of a metal container having an inner compartment filled with calcium chloride round which the inhaled oxygen passes before entering the breathing tube. This calcium chloride is in crystal form which liquefies when subjected to heat. Since its liquefying temperature is 86° F., a considerable quantity of heat is absorbed as this occurs; the inhaled air is therefore kept cool by this action. This is a practical example of the use of the latent heat of fusion dealt with in Chapter 1.

From the cooler the oxygen is carried to the mouthpiece by a corrugated breathing tube. A similar tube on the other side returns the exhaled air to the breathing bag. Mica valves are incorporated in the tubes to prevent flow in the reverse direction.

The mouthpiece is of soft vulcanised rubber fitted to a metal connecting piece, and is shaped to fit comfortably between the lips and the gums. Respiration is carried out entirely through the mouthpiece, a spring clip fitted with rubber pads being used to prevent inhalation through the nose.

A skull cap or other headgear is used to hold the mouthpiece comfortably in position; goggles are supplied with the apparatus for use as required.

The whole equipment is carried on a leather harness, with the oxygen cylinder at the rear and the breathing bag in front, so that the weight is evenly distributed. The complete apparatus weighs 32 lbs.

A combined tool and testing kit (Fig. 10) is supplied for use with sets. This consists of :—

(*a*) shifting spanner for general purposes.
(*b*) a flowmeter graduated in litres and half litres.
(*c*) tube for connecting flowmeter to reducing valve.
(*d*) two tommy spanners for removing diaphragm.
(*e*) screwdriver (small) for removing screw plug
(*f*) tongs for removing dome of reducing valve.
(*g*) screwdriver (large) for general purposes.
(*h*) double-ended spanner for gland nut and adjusting sleeve.
(*j*) screwdriver (split) for spindle nut.
(*k*) a test gauge.

Assembly and Testing. A " Proto " set assembled is shown in

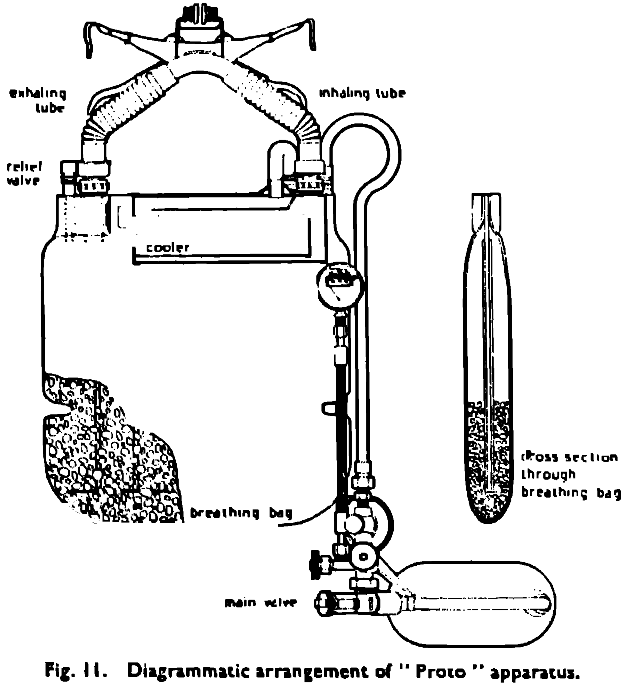


Fig. 11. Diagrammatic arrangement of " Proto " apparatus.

diagrammatic form in Fig. 11. Assembly should be carried out as follows :—

(i) Connect exhaling tube and cooler to the breathing bag and inhaling tube to cooler. Screw down nuts tightly and check relief valve for tightness.

(ii) Connect the test gauge to the oxygen cylinder, open main valve and note pressure.

If the cylinder is less than half full, replace with a fresh cylinder. Close main valve, remove test gauge and apply a thin film of water to the outlet to ensure that the valve is closing satisfactorily. On no account may oil of any kind be used on the valves owing to the fire risk in conjunction with oxygen.

(iii) Connect the valve group to the cylinder. When the joint has been tightened, connect the flowmeter to the oxygen supply tube, open main valve and note the rate of flow, which should be exactly 2½ litres per minute. Turn off main valve and watch the flowmeter and pressure gauge. The rate of flow should remain constant at 2½ litres per minute until the needle of the pressure gauge reaches zero.

(iv) Remove flowmeter, pass oxygen supply tube through the bend of the cooler (Fig. 12, *left*) and screw on to the inlet of breathing bag.

(v) Provide a bath or tank of water large enough to receive the whole of the apparatus, and completely immerse the high-pressure side of the apparatus (*i.e.*, cylinder and valve group, but not the pressure gauge).

Hold a thumb firmly over the mouthpiece orifice so as to avoid loss of oxygen, which will be required later for testing the low-pressure side of the apparatus. Turn on the main valve and watch carefully. If any of the joints are defective, bubbles will be seen forming round them and rising to the surface. Tighten any such defective joints until the bubbles cease. Care should first be taken, however, to ensure that all washers are in position and in good condition.

(vi) Close the pressure gauge valve. If the connection between gauge and tube is satisfactory the needle will remain stationary. If the needle falls tighten the joint, taking care not to use undue force. If difficulty is experienced in eliminating a leak a new washer should be fitted. The joints should never be tightened by force to prevent a leak, as the cause, if a slight tightening will not cure the trouble, is invariably a faulty washer.

(vii) Open the by-pass valve momentarily to inflate bag and immerse the low-pressure side of the apparatus (*i.e.*, breathing bag, cooler, breathing tubes and mouthpiece) holding a thumb in position over the mouthpiece orifice as before. Watch carefully for bubbles and rectify any leaks.

(viii) Close main valve, remove apparatus from bath, dry thoroughly and fit on canvas bag and carrying harness.

The apparatus is now ready for use and should not be tampered with until required.

Putting on the Apparatus. (i) Put on harness squarely and comfortably, care being taken to ensure that the reducing valve fits well down on the left hip; the shoulder straps lie squarely and are not doubled up; the pressure gauge and oxygen supply tubes are leading correctly; the oxygen cylinder is squarely in the middle of the back and that all straps are secured and tucked away (Fig. 12, *right*).

(ii) Put on skull cap, if provided.

(iii) Take out rubber plug, insert mouthpiece and adjust it comfortably in position, inhaling and exhaling through the nose.

(iv) Open main valve and lock it in position with safety bolt and take a reading of the pressure gauge to ensure that sufficient oxygen is available.

(v) Hold the nose-clip in the right hand and the by-pass valve in the left. Take a deep breath through the mouth to draw out any nitrogen which may be in the bag, and exhale through the nose. Open the by-pass valve sufficiently to inflate the breathing bag moderately, holding the breath meanwhile. Close by-pass valve, take two breaths, exhaling through nose, and put on the nose-clip.

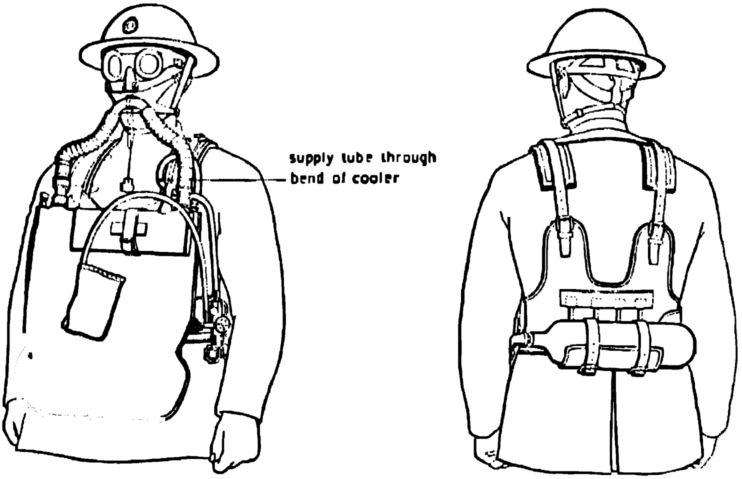


Fig. 12. "Proto" apparatus correctly fitted on wearer. Left: front view. Right: back view.

The wearer is now being supplied with pure oxygen from an independent supply and can move about unrestrictedly in any atmosphere.

Operation. If an oxygen breathing apparatus of the type described above has been correctly assembled and put on it will call for little further attention, and the wearer can safely leave it to its own business. The only items which need be remembered are :—

(*a*) The pressure gauge should be consulted from time to time to see how much oxygen remains in the cylinder, and therefore how long the wearer can remain in a poisonous atmosphere. The scale is divided into a number of sectors, each of which represents 5 atmospheres of pressure or 2½ minutes of time. A red line at 120 atmospheres indicates the position of the needle when the cylinder is full.

The gauge should show a reading throughout the period when the set is in operation and if consulted at regular intervals will keep the wearer informed of the amount of oxygen left in the cylinder. As explained above, the pressure-gauge valve is provided solely to prevent leakage of oxygen should the gauge or its flexible cable become damaged. It should never otherwise be closed.

When the needle registers " zero " there is still a slight margin of safety as the supply of oxygen in the breathing bag will last for a short period (under normal conditions about five minutes).

(*b*) When the set has been in use for some time, particularly if no strenuous work has been undertaken, the bag will be found to become unduly inflated, and some of the excess contents should be released by means of the relief valve.

The fact that the bag inflates so much as to become obtrusive is in itself a sufficient reminder that the relief valve should be used. Breathing will also be found to become slightly restricted as the bag fills ; this should be regarded as a warning to use the relief valve.

(*c*) If the wearer is working under exceptionally arduous conditions, or indulging in short periods of violent effort, the regulated supply of 2¼ litres per minute may temporarily be insufficient for his needs, and a feeling of restriction may be experienced. When this occurs the by-pass valve should be opened momentarily to give an increased supply. It will also be found beneficial after working in a heated atmosphere for some time to discharge the accumulated gases in the breathing bag by using the relief valve, and flush out the bag with a fresh supply of oxygen from the by-pass valve.

The by-pass valve serves also as a secondary means of supplying oxygen to the bag in the event of failure of the reducing valve.

(*d*) The carbon dioxide absorbent which fills the communicating compartment between the two halves of the breathing bag is so placed that the movements of the wearer when walking or at work automatically rub off the carbonated surface. If caustic soda is used as the absorbent material this action should be assisted at intervals by shaking the breathing bag, thus exposing a fresh surface for the absorption of carbon dioxide. The bag should not be shaken if granular absorbent is used.

(*e*) Should the calcium chloride in the container become liquid owing to the apparatus having been used in a heated atmosphere, its cooling properties can be restored by immersing the cooler in cold water. The filler cap should be firmly secured to prevent water coming in contact with the calcium chloride.

Calcium chloride will retain its properties almost indefinitely, but, as it is subject to very slight loss, should be topped up at intervals to maintain the level in the cooler. To do this, a sufficient quantity of calcium chloride should be heated slowly until it liquefies, and then poured into the inner chamber by means of the screw cap at the end of the cooler. The cap should then be replaced and the cooler immersed in cold water to reset the calcium chloride.

Re-charging. When the oxygen in the cylinder is exhausted, the wearer must return to respirable air to re-charge the apparatus. If the apparatus is to be used again immediately, the spent cylinder should be unscrewed from the valve group and a fresh one fitted. The carbon dioxide absorbent in the breathing bag must also be renewed.

The respirator tubes, cooler and relief valve should be unscrewed and the breathing bag removed from the canvas carrying bag before emptying out the used absorbent, care being taken to ensure that no particles of absorbent lodge in the shoulders of the bag or in the screwed connections of the relief valve, respirator tubes or cooler.

A fresh charge of absorbent, which is supplied in airtight tins each containing a complete charge, should then be poured into the bag, care being taken to ensure that an equal amount goes into each side of the compartment. A special pourer with a divided outlet can be used to facilitate this operation. If the lid of any of the tins of absorbent is found to be loose the absorbent should be thrown away as the air will have destroyed its efficiency.

As soon as the bag is re-charged it should be replaced in the canvas carrying bag and the mouth fastened by means of the steel clamps and wing nuts. The apparatus should then be assembled and tested as before, after which it is ready for further use.

If the apparatus is not to be used again immediately, the india-rubber bag should, if a caustic soda or coke absorbent has been used, be washed out thoroughly with warm water and dried inside with a clean cloth or towel. If granular absorbent has been used the bag need only be dusted with a dry cloth. The breathing tubes, rubber mouthpiece and goggles should be washed with yellow soap and warm water. When all parts are thoroughly dry the apparatus should be re-charged and re-assembled as before, the indiarubber plug being tightly inserted into the mouthpiece to prevent access of air to the absorbent. The goggles, if used, should be treated with an anti-dim preparation and stowed away with the set.

Care and Maintenance. If the " Proto " apparatus is maintained in good condition and the instructions given above are carefully adhered to, little adjustment should be needed over long periods of use. The following points should also be observed :—

(i) *No oil or grease of any kind should be used for lubricating the cylinder valve, gauge valve, reducing valve or other fittings.* Never under any circumstances should oil or grease be allowed to come into contact with the rubber breathing bag or mouthpiece. The action of oxygen on grease or oil causes rapid oxidation and may result in spontaneous combustion or explosion.

(ii) Never use undue force either on connecting nuts or on the main valve. Force used on the main valve may damage the thread and impair the seating of the valve. If difficulty is experienced in making any joint, fit a new washer.

(iii) Never open the by-pass while a flowmeter is connected, as this may damage the meter.

(iv) Never allow the metal parts, such as main valve, connecting nuts, etc., to be knocked, either when being carried or when stowed on the appliance as such treatment may cause slight oxygen leaks which will be difficult to cure.

Adjustments. (i) REDUCING VALVE. The reducing valve is set by the makers to give a supply of 2½ litres of oxygen per minute ; it should on no account be tampered with unless a flowmeter test shows that the rate of flow varies from this figure, and then only by an experienced person.

To test the reducing valve, connect it to a cylinder of oxygen containing not less than 30 atmospheres and screw on a flowmeter. When the main valve is open the top of the bobbin should rise and remain stationary at the line indicating 2½ litres per minute. (The flowmeter should be held in a vertical position throughout the test to prevent friction of the bobbin on the side of the gauge.)

As was explained in the general description of the apparatus the rate of flow is governed by the degree of pressure exerted by the spiral spring upon the diaphragm, which pressure is controlled by an adjusting sleeve. Any desired alteration in the rate of flow can therefore be effected by varying the pressure of this spring.

If the flow is less, or more, than 2½ litres per minute, the locking nut should be loosened and the adjusting sleeve screwed in the appropriate direction until the flowmeter registers 2½ litres per minute. Turning the sleeve in a clockwise direction will increase the flow, and *vice versa*.

When the rate of the flow has been adjusted the main valve should be closed and the flowmeter and pressure gauge watched. The bobbin should remain at 2½ litres until the pressure gauge falls to zero.

If the bobbin does not remain stationary, but falls before the pressure gauge reaches zero, the reducing valve is not functioning correctly and should be stripped down and examined.

The fault may be either :—

(*a*) A hard or perished diaphragm. *Remedy ;* this should be renewed.

(*b*) A scored or faulty ebonite seating on the floating valve. *Remedy ;* this should be renewed.

(*c*) The back pressure disc may be loose. *Remedy ;* the perforated screw plug, which holds it in position against the fibre washer, should be tightened down.

(*d*) The floating valve seating may be set too far from the oxygen inlet jet. *Remedy ;* unscrew the spring until it exerts no pressure on the diaphragm. Screw down the floating valve seating very lightly until it is just in contact with the jet, and then unscrew it a quarter to half a turn until the locking washer can be inserted with its projecting portion properly in position. Do not use excessive force, as this may damage the ebonite seating.

(*e*) Test the contents of the cylinder of the apparatus by the standard gauge and then check the gauge attached to the set by comparing its reading. A slight minus error can be ignored as it shows less oxygen than there actually is, but a plus error of more than 10 atmospheres is serious, and the gauge should be sent in for readjustment. Tests should be done with varying pressures in the cylinder.

Always remember to insert the locking washer and the metal filling washer before screwing on the blank cap. Screw the cap on tightly; any leak through the cap will affect the working of the reducing valve and will result in loss of oxygen.

It is advisable, before adjusting the reducing valve as described above, to unscrew the valve group connecting nut and examine the gauze filter. This may be found to be dusty or coated with verdigris, and thus be impeding the supply of oxygen. It should be carefully removed with the tool provided for the purpose, cleaned with carbon tetrachloride and carefully replaced. If it is found to be punctured or damaged it should be discarded and a new filter inserted.

(ii) MAIN VALVE. The main valve is of robust construction and should call for no adjustment over long periods. Slight leaks may, however, develop from time to time, which should be dealt with as follows :—

Leaks which occur with the valve in the open position can usually be cured by tightening the gland nut slightly. If this does not cure the leak the spindle washer may be scored or have worn hard, or

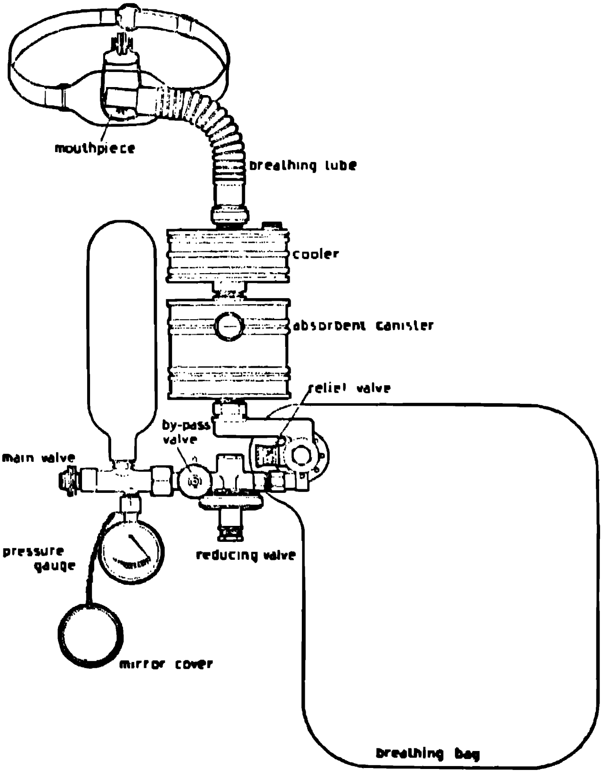


Fig. 13. Diagrammatic arrangement of "Salvus" half hour self-contained closed circuit breathing apparatus.

the spiral spring may have become too weak. The remedy in each case is to replace the faulty part.

Leaks in the closed position are due to the valve having been screwed down too hard, thus distorting the fibre valve. The only remedy is to dismantle and insert a new fibre valve.

Tests. If adequate gauge-testing apparatus is not available the standard gauge and flowmeter should be returned to the makers every two years for testing, and the complete apparatus once every three years.

There are several other types of closed circuit regenerative breathing apparatus used in the Service, perhaps the best known of which are the " Salvus " and " Fireox." These are similar in design and operation to the " Proto " apparatus described above, but are of lighter construction and are designed for short period use only.

(*b*) *Salvus.* The " Salvus " breathing apparatus (Fig. 13) is of the closed circuit regenerative type employing oxygen. It consists of a cylinder containing 3·5 cu. ft. of oxygen at 1,800 lbs. per sq. in. pressure, a valve group, breathing bag, carbon dioxide absorbent and cooler, all of which operate on the same principles as in the " Proto." The reducing valve is, however, adjusted to give a flow of 2 litres per minute. The valve group is, however, connected direct on to the breathing bag, which is of simple construction, and respiration is carried out through one breathing tube only ; both the cooler and the absorbent container being inserted between the tube and the breathing bag. A diagrammatic arrangement of the apparatus from which the difference in layout from the " Proto " can be seen, is given in Fig. 13.

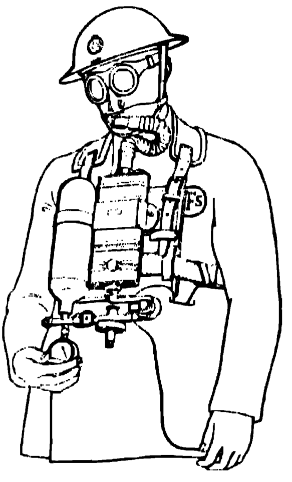


Fig. 14. Front view of " Salvus " apparatus, showing method of reading gauge.

The apparatus is assembled and tested as already described for the " Proto." Putting on is simpler, as the whole of the apparatus is worn on the chest and a simpler form of harness is therefore used. The apparatus is supported by a belt which is strapped round the body and is hung by a neck and back strap with adjustable straps and buckles at the front, to suit the height of the wearer.

Starting up is accomplished in the same sequence as for the " Proto." There is, however, no locking nut on the main valve, and the position of the pressure gauge on some models necessitates the use of a special mirror cover to enable a reading to be taken (Fig. 14). Modified sets have, however, recently been produced on which the gauge is led to a convenient position near the top of the oxygen cylinder, either a flexible lead or a rigid pipe being used. Re-charging is also similar, the only difference being that the carbon dioxide absorbent is not carried in the breathing bag but in a metal

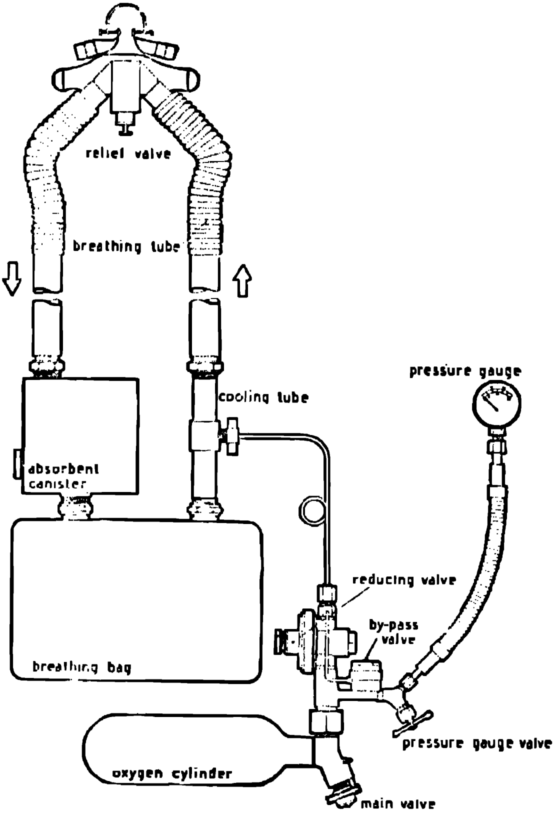


Fig. 15. Diagrammatic arrangement of " Fireox " apparatus.

canister, which is re-charged by emptying out the used absorbent and refilling from a fresh tin.

The " Salvus " apparatus weighs only 18½ lbs. and is intended primarily as a short-period set.

(c) *Fireox*. The " Fireox " is also a closed circuit regenerative apparatus employing oxygen. It comprises a cylinder containing 3½ cu. ft. of oxygen at 1,800 lbs. per sq. in. pressure, to which is attached a valve group and pressure gauge similar to those used on the " Proto " and " Salvus " sets. The layout of the apparatus (Fig. 15) is therefore slightly different, the oxygen being fed from the valve group direct into a cooling tube attached to the inhalation tube and only entering the breathing bag after exhalation.

Inhalation and exhalation tubes are provided, as with the " Proto," but these are carried back over the shoulder to a combined carrier and protecting cover, worn on the back, in which the whole of the apparatus is housed (Fig. 16, *right*). The inhalation and exhalation valves, instead of being located at the ends of the breathing tubes, are incorporated in a special fitting in front of the mouthpiece. The relief valve is also incorporated in the fitting.

The difference between the " Fireox " and the two types of oxygen breathing apparatus previously described is, however, more apparent than actual, and assembly, testing, starting up and re-charging are all carried out as described. The by-pass and relief valves, however, though similar in essentials, are slightly different in construction from these parts on either of the other sets. The by-pass valve consists of a hexagon nut in the centre of which is a ball valve actuated by pressure of the thumb (Fig. 16, *right*).

The relief valve is housed in a special fitting in front of the mouthpiece and between the two breathing tubes (Fig. 16, *left*). It is operated by pulling down the spindle, thus allowing the excess air to escape from the bag *via* the breathing tube. The spindle should be pulled down only on exhalation, and the wearer should blow out strongly whilst it is open. A non-return valve prevents outside air from being inhaled when the relief valve is opened. The complete " Fireox " weighs 27 lbs.

The advantages of closed circuit self-contained regenerative oxygen breathing apparatus of the types described above are :—

(i) It is vastly superior to all atmospheric type breathing apparatus as the wearer is independent of the atmosphere and can therefore move about freely in poisonous gases.

(ii) The controlled feed given by the reducing valve enables the duration of the supply to be calculated for any state of the cylinder. The fact that the duration of the supply is known and is not subject to variation by reason of sudden strenuous exertion also gives increased confidence to the wearer.

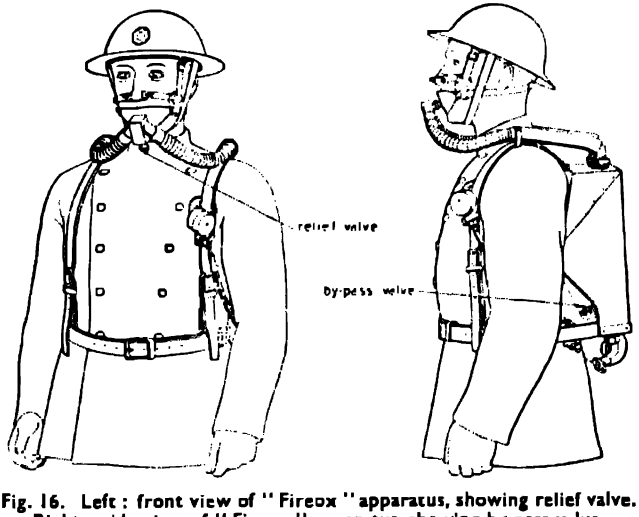


Fig. 16. Left : front view of " Fireox " apparatus, showing relief valve. Right : side view of " Fireox " apparatus, showing by-pass valve.

(iii) The apparatus is comfortable to wear, the parts being so disposed (in one type) that the weight is equally distributed back and front. It is, moreover, flexible and conforms to the movements of the body without undue restriction.

(iv) The disposition of the various parts of the apparatus (in the "Proto" and "Salvus" types) makes it possible for the wearer to carry an insensible person on his back without difficulty.

(v) The use of a mouthpiece is to be preferred for Fire Service work, since, as the whole of the face is not covered, it is cooler, and will fit anyone.

(vi) The use of oxygen in place of atmospheric air is beneficial to the wearer and assists him to some extent in carrying out strenuous work. Instead of only a small portion of the air inhaled being used, the whole supply is beneficial.

(vii) If the wearer of the apparatus is trapped in an irrespirable atmosphere, for example by the collapse of a building, he can by turning off his cylinder valve and manipulating this as required, make his oxygen supply last for a greatly increased length of time and thus increase his chance of being rescued alive.

The disadvantages are :—

(i) The design is such that a course of training is required to enable personnel to assemble and use the set.

(ii) Re-breathing oxygen may be a disadvantage in certain cases, as for instance in a man with stomach complaints.

(iii) Men working together can only communicate with one another by signals owing to the use of a mouthpiece. A full mask can be used with the apparatus to overcome this difficulty but for general use a mouthpiece is preferable.

(iv) It requires continual if slight attention in use (operating relief valve, by-pass valve and so on).

(v) A second man is necessary to change a cylinder whilst the set is being worn.

(vi) In re-charging the set not only must the cylinder be changed but the used absorbent must be removed and a fresh charge substituted. This necessitates carrying spare charges of absorbent on the appliance.

(vii) Unless special equipment for re-charging the cylinders from larger oxygen cylinders locally is installed, the cylinders must be sent away for re-charging. This necessitates the provision of a large stock of spare cylinders.

(viii) A number of small spares must be carried with the set.

The respective merits of the various types of breathing apparatus described above may be summed up in general terms as follows :—

(*a*) All self-contained types are preferable to any atmospheric type.

(*b*) The sole advantage of the atmospheric types is the low initial cost, and they should be used only for short-period work within easy reach of breathable air. They may be regarded as being out-dated for general Fire Service work, although they have been found useful for dealing with fires in ships' holds.

(*c*) Of the self-contained types, the oxygen regenerative apparatus is to be preferred for extended work to the compressed air type, which is, however, eminently suitable for short-period work.

LINE SIGNALS

Men wearing self-contained breathing apparatus should always work in pairs and except in very special circumstances should not have lines attached to them.

On occasion it may be found desirable for them to trail a bobbin line in order that they may be able readily to retrace their steps—but the bobbin line is not used for signal purposes.

The bellows type smoke helmet using air tubing is considered to be obsolescent and no standard line signals for use in conjunction with it have been issued.

There may be occasions when a fireman has to be lowered down a shaft, a well, or over a cliff in order to effect a rescue or for other reasons. In these circumstances he should be lowered on one line and he should have a second line attached to him for signalling purposes.

The following signals should be employed :—

Signal on Line	*Given by Wearer*	*Given by Attendant*
1 pull . . .	I am all right.	Are you all right ?
2 pulls . . .	Pay out more line.	I am paying out more line.
2 pulls—pause—2 pulls	Stop lowering.	I am ceasing lowering.
3 pulls . . .	Haul in slack line, or Haul up.	I am hauling in slack line, or I am hauling up.
Repeated, sharp pulls .	Danger—help me out.	Danger—come out at once.

Signals Must be Repeated. In every case when signals are employed they should be acknowledged by the recipient of the order repeating the signal to show that it has been understood and is being acted upon.

PART I CHAPTER 12

RESUSCITATION APPARATUS

RESUSCITATION is the process by which a person who is suffering from oxygen starvation and apparently dead, is induced to resume normal respiration. Such a process is necessary to revive persons suffering from carbon monoxide poisoning, smoke or de-oxygenated atmospheres generally, drowning, electrical shock, and all other cases in which respiration has for any cause ceased or been impeded.

Resuscitation can be applied by manual technique which induces normal respiration, or by means of apparatus which supplies pure oxygen, oxygen and carbon dioxide or air and carbon dioxide, thus exercising a stimulating effect on the respiratory centre of the brain and accelerating the recovery of the patient.

The following figures, produced as a result of experiments conducted by the late Professor J. S. Haldane, M.B., F.R.S., give some indication of the respective values of these different methods. It was found that to eliminate carbon monoxide from the blood of a patient who had breathed a dangerous concentration took :—

1. Breathing air	140 minutes.
2. Breathing oxygen	85 ,,
3. Breathing air plus 5 per cent. carbon dioxide	80 ,,
4. Breathing oxygen plus 5 per cent. carbon dioxide	20 ,,

To understand the reasons for this pronounced effect of carbon dioxide, some account of the mechanism of the respiratory centre in the brain is necessary.

From the brief account of the respiratory system given in the previous chapter, the importance of the involuntary movements of the chest wall and diaphragm in controlling the expansion and contraction of the lungs will have been appreciated. These movements are governed by the respiratory centre in the brain which is sensitive to the amount of carbon dioxide in the blood. If the percentage is small, breathing will be sluggish and shallow, as the percentage increases, breathing becomes more rapid and much deeper. As was explained in the previous chapter, when energy is expended more oxygen is consumed and more carbon dioxide produced. This rise in the percentage of carbon dioxide in the blood stimulates the respiratory centre to increase the depth and frequency of breathing, more oxygen is supplied and more carbon dioxide escapes out of the blood in the lungs and is exhaled.

When the body is functioning normally, sufficient oxygen is brought by the blood to the centre to keep the cells functioning and sensitive to any stimuli, including the normal carbon dioxide content of the blood. When, however, the supply of oxygen is cut off, these cells fail and the respiratory centre becomes moribund or paralysed and refuses to react to normal stimuli. Breathing stops, the interchange of gases in the lungs comes to a standstill and oxygen is no longer transported to the tissues and cells.

It is a lack of oxygen, rather than an excess of carbon dioxide, that induces the depression of the respiratory centre; it is therefore imperative to get oxygen into the blood by artificial respiration. After carbon monoxide poisoning, carbon dioxide administration stimulates the respiratory centre to heightened activity and accelerates the removal of the carbon monoxide.

When oxygen reaches the moribund respiratory centre the whole mechanism begins to function again, spontaneous respiration commences, the oxygen supply is maintained, sensitivity of the centre is restored, natural breathing returns and the asphyxia is relieved.

If in a normal man approximately 5 per cent. of carbon dioxide is added to the inspired air, the volume of air which passes through the lungs in a given period is increased by 200 to 300 per cent., but this does not necessarily apply to a person in whom respiration has nearly ceased.

ARTIFICIAL RESPIRATION

It must always be remembered, however, that in conditions where breathing has ceased altogether, manual artificial respiration must be carried out in order to draw in sufficient oxygen either with or without carbon dioxide to stimulate the respiratory centre.

1. SCHÄFER'S METHOD

There are various methods of artificial respiration, but Schäfer's method is the one usually adopted and is the one subsequently described. On no account must it be applied, however, if the patient is suffering from chest or internal injuries.

It should never be assumed that a patient is dead because breathing is not apparent, and immediate action must, in all such cases, be taken to render breathing possible. The air passages must be cleared of all obstructions, any pressure preventing the expansion of the chest must be removed, and there must be an abundance of fresh air made available for the patient to breathe.

If natural breathing is seen to be failing, or cannot even be discerned, then manual artificial respiration to restore it must be resorted to immediately.

First, any foreign bodies should be removed from the patient's mouth and throat (chewing gum, false teeth, etc.); the patient is then laid in a prone position face downwards, one arm extended above the head, the other bent to form a pillow, and the face turned to one side resting on the forearm so that the nose and mouth are away from the ground and free for breathing.

Time should not be wasted on loosening the patient's clothing, nor need the tongue be drawn out, as it will fall naturally towards the lips when the body is turned on its face.

When the patient is lying face upwards it is sometimes possible to induce air to enter the chest by pressing the abdomen and then suddenly relaxing the pressure. This may be done before turning the patient over on his face.

To turn over a patient in the prone position, stoop at his side, place his arms close to the body, cross his far leg over his near leg, and, whilst protecting his face with one hand, grasp the clothing at the hip on the opposite side of the body with the other hand and pull the patient over.

To induce exhalation after the patient has been placed in the correct position already described the operator should kneel astride, or on one side of the patient facing his head and sitting on the heels. Then place the hands on the small of the patient's back, their lower edges just clearing the top of the pelvis (or the little finger just touching the lower rib), the wrists nearly touching, the base of the thumbs as near each other as possible without strain and the fingers passing over the loins on either side, being pointed towards the ground but not spread out (Figs. 1 and 3).

The position of the hands is important because pressure should only be applied to the lowest ribs which are free to move, and, consequently, not in danger of breaking when pressure is applied.

With the arms held straight, bend the body from the knees, and, somewhat straightening the hip-joints, swing slowly forward so that the weight of the body is gradually brought to bear upon the patient and conveyed directly downwards. The elbows should not be bent and no exertion is required as all the pressure necessary is given by the weight of the operator's body.

The resulting effect is that the patient's abdomen is pressed against the ground and by the consequential pressing of the abdominal organs against the diaphragm the diaphragm rises, and air, along with any water which may be present, is driven out of the lungs, thus producing exhalation.

To induce inhalation swing the whole body slowly backwards to its original position so as to remove the pressure completely. The organs now assume their former position with the result that air passes into the lungs, thus producing inhalation.

These movements are alternated by means of a rhythmic swaying of the body forwards and backwards from the knee joints at a rate of, approximately, twelve times a minute for the double movement of compression and relaxation. The pressure period should occupy two seconds and the period of relaxation three seconds, and to ensure regularity the worker should count evenly up to five on each double swing.

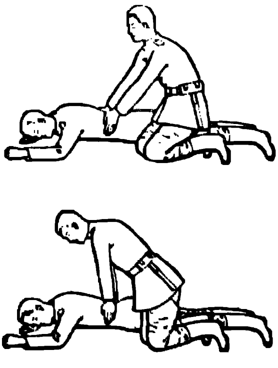


Fig. 1. Schäfer's method of artificial respiration.

2. GENERAL

A brief return of natural respiration should not be taken to mean that the need for resuscitation has ceased. Not infrequently the patient, after a temporary recovery of respiration, stops breathing again. The patient must therefore be watched, and if natural breathing stops, artificial respiration must be resumed at once.

Manual artificial respiration must be continued until respiration is restored or a doctor pronounces life to be extinct. Definite evidence of death, *e.g.*, *rigor mortis*, should be insisted upon before abandoning artificial respiration. Cases are on record in which the rescuers have persevered after life has been declared extinct and have succeeded in saving the life of the patient.

An unconscious person becomes cold very rapidly and this means an added strain on an already weakened vitality. As far as possible, therefore, the patient should be kept covered whilst artificial respiration is being given. Blankets and hot water-bottles should be used to keep the patient warm, and the bottles refilled at intervals. It should be remembered that an unconscious patient cannot say whether he is being burned. The bottles should not, therefore, be too hot.

RESUSCITATION APPARATUS

Manual artificial respiration is, of course, necessary in all cases in which breathing has ceased. Many lives have been saved by methods such as are described above, without other assistance. The use of resuscitation apparatus, however, not only greatly increases the patient's chance of recovery but also, owing to the fact that poisonous gases are expelled from the blood more rapidly, reduces the after-effects of oxygen starvation and so accelerates complete recovery.

It is now generally accepted that the best method of resuscitation is by artificial respiration together with the administration of oxygen either with or without a small percentage of carbon dioxide, with the exception of cases where the patient is suffering from carbon dioxide asphyxia. Carbon dioxide artificially administered, either with or without oxygen, forms a valuable stimulant to the respiratory centre and will assist in speeding up the return of normal respiration. Where, however, the victim is suffering from suffocation caused by carbon dioxide it is probable that the quantities of this gas present in the body of the victim have already exerted their maximum stimulatory effect and its use for resuscitation purposes will be attended by a less marked reaction.

In such cases, therefore, great emphasis should be laid on the desirability of continuing artificial respiration and allowing the respiratory centre of the patient to resume functioning without the forced stimulus provided by further large quantities of carbon dioxide. The simultaneous administration of oxygen either with or without a small proportion of added carbon dioxide will, however, greatly assist the patient.

It is desirable from a medical point of view that the return to normal respiration should not be artificially hastened too rapidly, since the strain on the patient's resistance, already severely taxed, may result in a later relapse with more serious consequences.

The administration of oxygen presents the best prospects of successful resuscitation, but in order to stimulate the respiratory system to inhale it, a limited quantity of carbon dioxide may be added. It has been found that the addition of about 7 per cent. carbon dioxide to increase the amount present in the blood gives the best results.

There is, for instance, a mixture of 93 per cent. oxygen and 7 per cent. carbon dioxide especially produced for the treatment of carbon monoxide poisoning, acute alcoholic poisoning, morphine poisoning, etc., respiratory failure due to electric shock, drowning and various other causes. This gas is stored in cylinders painted black with a green and white band painted round the neck below the valve; oxygen is stored in cylinders painted black. A cylinder should never be used for any gas or mixture of gases other than as indicated by the British Standard Identification colour for that particular cylinder.

There are several types of resuscitation apparatus in use in the Service, which may be classified broadly under the following headings :—

1. Apparatus where oxygen, or oxygen and carbon dioxide, is administered from cylinders by hand control.
2. Apparatus where oxygen, or oxygen and carbon dioxide, is administered from cylinders automatically by the patient's inspiratory effort.
3. A simple form of apparatus for emergency use for administering carbon dioxide and air by means of carbon dioxide capsules, and
4. A rocking resuscitation stretcher which is, in effect, an apparatus for applying artificial respiration by rocking the patient.

I. THE HAND-CONTROL TYPE OF RESUSCITATION APPARATUS

In this type, oxygen or a mixture of oxygen and carbon dioxide is made available to the patient through a suitably constructed face mask. The rate at which the gas is fed to the wearer is controlled by the operator.

A typical example of this type of apparatus (Fig. 2) consists of a steel cylinder (*a*) of 10 cu. ft. capacity when fully charged at 120 atmospheres, which is fitted with a main valve (*b*) and a reducing valve. An attached pressure gauge (*c*) indicates the pressure and consequently the approximate quantity in the cylinder.

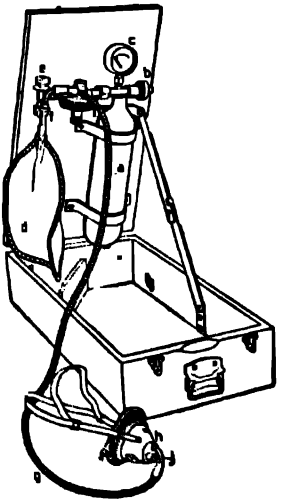


Fig. 2. Resuscitation apparatus —hand-control type.

The supply flows from the cylinder into a flexible bag (*d*), the flow being regulated by means of a fine adjustment valve (*e*). The supply then flows from the flexible bag through an inlet or inspiratory valve (*f*), from which the patient inhales, into a flexible tube (*g*) leading to a mask (*h*) which covers the nose and mouth.

The mask is fitted with an outlet, or exhaling valve (*j*), which allows the exhaled air to pass to atmosphere.

When using the apparatus the first step should be to verify that the cylinder is fully charged and that all joints and connections are quite tight. Place the patient face downward in the prone position, turn on the main valve, carefully and gradually open the fine adjustment valve and then arrange the mask on the patient's face. The fine adjustment valve should be so adjusted as to keep the flexible bag about half full, as over-inflation will cause wastage.

Manual artificial respiration must, of course, be commenced immediately in all cases of acute asphyxia and the resuscitator brought into use in conjunction therewith at the earliest possible moment.

2. THE LUNG-CONTROLLED TYPE OF RESUSCITATION APPARATUS

This type works on much the same principles as the compressed air breathing apparatus already described, that is, gas is only released from the cylinder as it is required. It is, of course, more complicated in construction than the hand control type of resuscitation apparatus, but is more economical in that only the amount of gas that is inspired by the patient is delivered.

The apparatus is made in different sizes, having either one or two oxygen cylinders, but a description of the single cylinder type will suffice as the principle of the " lung control " is the same.

(*a*) *Construction.* The apparatus (Fig. 3) comprises a 15 cu. ft. cylinder (*a*) with an attached main valve (*b*), a breathing bag (*c*) which contains the lung-operated gas admission mechanism, a flexible breathing tube (*d*) and a face mask (*e*). There is also a by-pass valve (*f*) to enable gas to be admitted to the face mask independently of the lung-operated mechanism, and the face mask itself is fitted with an air admission orifice and shutter (*g*) and an exhaling valve (*h*).

The pressure gauge (*j*) indicates the pressure in the cylinder which, when fully charged, should be 120 atmospheres.

When using the apparatus, open the cylinder valve and apply the mask to the patient's face with the air orifice closed. Make sure that the mask fits properly and is held securely in position as any leaks round the edges will cause air to be drawn in.

The gas is then automatically delivered by the patient's inspiratory effort, which causes the bag to collapse and actuate the lever controlling the gas admission valve.

(*b*) *By-pass Valve.* The state of the patient's breathing can be determined by noting the movements of the flexible bag, and *if the breathing is very shallow, or has ceased, the by-pass valve must be opened* and thus allow the gas to pass from the cylinder direct to the bag and thence to the mask. Do not, however, over-inflate the bag when using the by-pass as this will cause a wastage of gas which will blow out through the exhaling valve on the mask.

When the patient is breathing spontaneously the by-pass valve may be closed, as all the gas required will then be taken by means of the bag mechanism which only admits gas on inhalation.

(*c*) *Control of Air Supply.* When normal breathing is re-established, the amount of gas administered may be reduced by opening the shutter of the air-admission orifice. When this is slightly opened the patient will inhale partly air and partly gas. By increasing the opening more air and less gas will be inhaled. When the shutter is opened completely all air and no gas will be breathed. If the respiration should appear to become feeble again the shutter should be closed and artificial respiration resumed.

The component parts of both the above types are self-contained in strong metal or wooden carrying boxes, and the apparatus itself should be kept in a clean, dry place and be well cared for.

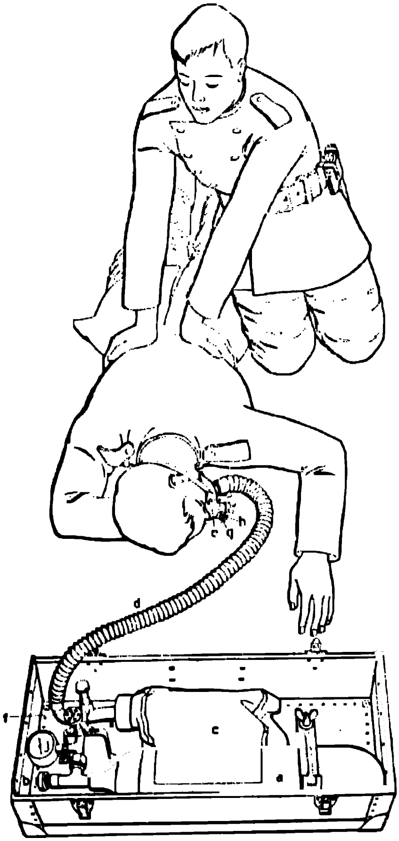


Fig. 3. Resuscitation apparatus—lung-controlled type.

(*d*) *Testing.* The cylinders should be tested periodically to see that they contain the full pressure of gas (120 atmospheres) and, after testing, the cylinder valve must be screwed down tightly so as to prevent leakage.

The valves fitted on the masks are of rubber and these should be examined periodically to make sure that they are working freely and are not perished.

After use the mask and tube should be disconnected, washed in soap and water, rinsed well in clean water and allowed to drain. The mask should be disinfected by wiping out with a disinfectant of suitable strength.

When fitting a cylinder to the lung-operated type great care must always be taken not to bend the lever of the lung-operated mechanism inside the bag.

3. APPARATUS FOR ADMINISTERING CARBON DIOXIDE AND AIR BY MEANS OF CAPSULES

To employ the valuable stimulating properties of carbon dioxide without the drawbacks due to the weight of heavy cylinders, the use of small capsules of highly compressed gas, similar to those used for the home manufacture of soda water, has been developed. Such resuscitators do not supply oxygen and consequently are not so efficient for treatment in some cases, but their light weight and portability combined with relatively small cost make them a useful adjunct where larger apparatus is not available.

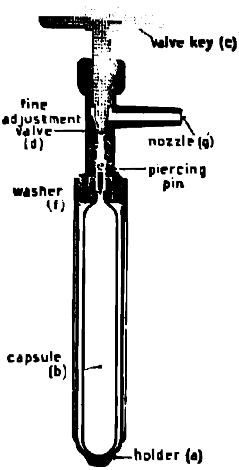


Fig. 4. Carbon dioxide and air apparatus—bulb and holder.

The model described below may be taken as typical of this class of resuscitator.

(*a*) *Construction.* The apparatus (Fig. 4) consists of a holder (*a*) in which is placed a sparklet bulb or capsule (*b*) and a valve key (*c*), which controls a fine adjustment valve (*d*).

The capsule of carbon dioxide for this model is 6¼ in. long and slightly over ¾ in. diameter, and contains 25 grammes of liquid carbon dioxide, which produces approximately 12¾ litres of gas, being sufficient for a six-minute supply at an optimum rate of 2 litres per minute.

(*b*) *Charging.* The apparatus is charged in the following manner. First, screw down the valve key (*c*) without using force, so as to close the fine adjustment valve, and then unscrew and remove the holder (*a*). Place a capsule in the holder and screw down rapidly as far as it will go. This operation presses the capsule neck against the washer (*f*), so making a gas-tight joint, and pierces the capsule by means of a piercing pin (*e*).

(*c*) *Operation.* (i) *Open Method.* To start the gas flowing, the resuscitator is held as nearly as possible in an upright position with the nozzle (*g*) and valve body firmly gripped between the thumb and fingers. The valve key is then gently turned in an anti-clockwise direction until the gas flows at the required rate through the nozzle.

When the supply of gas is exhausted, another capsule, if required, can be quickly inserted. The empty capsule is removed by first opening the fine adjustment valve (by unscrewing the key), so ensuring the discharge of all the gas, and then unscrewing the holder and removing the capsule by turning it in a clockwise direction as it is withdrawn, so as to prevent the guide washer retaining ring being unscrewed.

This method of administering carbon dioxide is known as the "open method." The resuscitator nozzle is held about 2 in. from the patient's nose and mouth, and the gas mixes with the inspired air. When necessary the patient must, of course, first be moved into respirable air.

As with other types of resuscitator, manual artificial respiration must be employed immediately in cases of acute asphyxia and kept up until normal breathing returns. The carbon dioxide should be given at the earliest possible moment and a high concentration of the gas can be used at first, bearing in mind the remarks already made regarding carbon dioxide asphyxia. The amount may be varied at will by opening or closing the fine adjustment valve or by varying the distance at which the nozzle is held from the face. Almost pure gas may be administered by covering the face with a handkerchief, and in this way one inspiration has frequently been the means of stimulating respiration.

After the first signs of a return of breathing, manual artificial respiration should be continued in an atmosphere of 5 to 10 per cent. carbon dioxide. This concentration may be obtained by a gentle flow of gas mixing with the inspired air when the resuscitator nozzle is held about 2 ins. from the patient's nose. As the effect of the gas is easily observed, no accurate gauge of the flow is necessary.

(ii) *Closed Method.* This type of resuscitator can also be used for the " closed method " of carbon dioxide administration by the addition of a bag and a face mask incorporating a carbon dioxide and air mixture fitment.

The resuscitator should be assembled as illustrated in Fig. 5, and at the average or artificial rate of respiration a mixture of approximately 7 per cent. carbon dioxide and 93 per cent. air is inhaled.

The resuscitator is charged as for the " open method." The gas regulator (*a*), which is attached to the mask, is then set at the "Air" position and the mask is placed on the patient's face, being held in position by the elastic band. The resuscitator is held in the upright position, with the nozzle and valve body firmly gripped between the thumb and fingers and the valve key gently turned to inflate the bag to an easy pressure without tension on the rubber.

The gas regulator is then set at the " Air and CO_2 " position and the carbon dioxide will then flow into the mask at approximately 2 litres per minute, mixing with the inspired air which is allowed free entry through the holes. This mixture, on inspiration, is approximately 7 per cent. carbon dioxide and 93 per cent. air. The valve key is then adjusted so as to allow a steady flow of gas into the bag. The apparatus is recharged and the empty bulb removed as detailed for the " open method."

Owing to the small size of the capsules used there should, of course, be an available reserve to meet emergency requirements. The empty capsules can be returned to the manufacturer for refilling, which is cheaper than purchasing further new supplies.

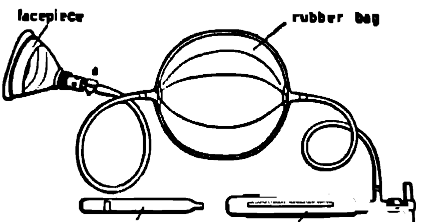


Fig. 5. Carbon dioxide and air apparatus, complete assembly.

4. THE ROCKING RESUSCITATION STRETCHER

Experimental research on resuscitation has shown that if means are provided to enable the body of an apparently asphyxiated person to be swung so that the feet and the head are alternately uppermost, the same effect is achieved as by manual artificial respiration. When the head is downwards the weight of the abdominal contents of the body pushes up the diaphragm and compresses the lungs, thus causing exhalation, whilst in the feet-down position the abdominal contents pull down the diaphragm, thus causing inhalation.

A special rocking stretcher which provides an alternative to Schäfer's method of manual artificial respiration has been designed to carry out this movement. Although this apparatus is not widely used in the National Fire Service a brief description of its construction and use is given, as it is possible that it may be encountered.

The apparatus (Plate 7, facing page 43) consists of a metal stretcher and a collapsible attached base. When the apparatus is assembled for use, the base forms a triangular shape in elevation, the broad portion of which rests on the ground and the stretcher becomes, in effect, a " see-saw " balanced on the apex of the metal base. As the body is well balanced, the duties of the operator are confined to tilting the stretcher at the required time intervals for breathing.

The patient is placed prone on the stretcher, the rocking being started immediately he has been secured by means of the attached straps, with his face in the padded groove provided, and his feet on one of the cross-members.

The tongue cannot fall back and water will drain from the lungs and stomach of an immersion case in a deliberate preliminary head-down position.

The apparatus is designed to take either a child or a large adult.

An attached mercury timing device indicates the correct timing of the movement on the basis of 15 complete cycles per minute, and also allows more time for inhalation then exhalation. Immediately the mercury ceases to flow the stretcher is smartly rocked through its full range, which is 100 degs.

It must, of course, be remembered that this is merely an alternative to Schäfer's method of manual artificial respiration, and, when available, oxygen, or oxygen and carbon dioxide, should preferably be simultaneously administered in cases of acute asphyxia. In this rocking method the operator is called on for considerably less physical exertion, and warmth, which is all-important, can be freely applied during resuscitation. The complete apparatus packs up flat and is easily stored and transported.

There are, in addition to the types previously described, forced breathing types of resuscitation apparatus, but in using this type of apparatus there is always a danger of the operator damaging the delicate tissues of the patient's lungs. The operator could, for instance, administer gas for a longer period than desirable or, conversely, extract it too quickly. For this reason no attempt has been made to describe any such apparatus, and its use cannot be recommended.

There is no standard issue of resuscitation apparatus to the National Fire Service, but as sets of the types previously described were used in many parts of the country prior to nationalisation, it is necessary for personnel to be acquainted with their construction and use, so that whenever called upon to operate them there shall be a minimum of delay.

Where such apparatus is provided, officers in charge should see that all personnel periodically practise the correct working methods (without necessarily using the gas) so that in case of necessity they may be conversant with resuscitation procedure.

PART I CHAPTER 13

SMALL GEAR

UNDER this heading are included all those items of gear carried by Fire Service vehicles and appliances which are not described in other chapters. It is not proposed, for example, to describe here the specialised equipment carried on emergency and foam tenders, or on turntable ladders, which will be found described in detail in the chapters dealing with those appliances. Various other associated items, such as lines, hose fittings, extinguishers, and hand-pumps are also described elsewhere, this first part of the *Manual* thus containing a complete survey of the gear used by the Fire Service.

Although the gear carried on a fire appliance presents rather a miscellaneous appearance if laid out beside the appliance, its selection is the result of years of experience, and the continual development of new, and the elimination of unwanted, items have resulted in an equipment which is logical, efficient and economical.

It is remarkable that, despite the number of regular brigades existing before nationalisation, and their diversity in almost every other way, the small gear carried on appliances was very largely standardised throughout the country. Local differences existed, of course, as was inevitable from the fact that the gear was purchased from private firms, who naturally tended to produce refinements in the various items to distinguish them from the products of their competitors.

In the main, however, the equipment carried was identical, and fell naturally into groups of associated tools. These are :—

1. Breaking in tools.
2. Cutting away tools.
3. Rescue gear.
4. Lights of various kinds.
5. Turning over tools.
6. Transport tools ; such as jacks, spanners, wheel-braces and other tools used for the maintenance of the vehicle or appliance, and finally (7.) a selection of special and miscellaneous equipment which varied with the type of appliance.

The gear issued with emergency appliances, being intended to cover as far as possible similar requirements, is essentially the same as that carried on the ex-regular appliances. It is possible, therefore, to regard the issue of small gear as being almost standardised.

To standardise the stowage of such gear, however, presents something of a problem, owing to the diversity in design of Fire Service appliances, both ex-regular and emergency. As far as possible, stowage should be standardised on lines laid down for the Service in respect of certain types of vehicles. Where the arrangement of the accommodation is such that the standard method of stowage is impossible, then gear should be arranged to approximate in location as closely as possible to any set standards. The advantages of standardised stowage are many, the principal one being that fresh crews can take over an appliance and know immediately where all items of gear are kept, thus greatly facilitating work in the dark and speeding up operations.

The rapid location of gear can be further simplified, with a little ingenuity in the use of hooks, slots, webbing straps and other fittings, by stowing the individual lockers so that all the gear contained in them is immediately visible on opening the lid or door. Further assistance can be provided, if required, by indicating the position of each item against its name on the gear list, and by pasting inside the lid of each locker a list of the gear it contains.

Small gear in general needs little maintenance, but should be inspected regularly and cleaned as required. Metal tools in particular should be kept scrupulously clean to prevent the formation of rust, and the wooden shafts of axes, spades and similar tools should be scrubbed periodically.

1. BREAKING IN TOOLS

Breaking in gear consists essentially of a number of heavy metal tools, which have been adapted for Fire Service use rather than specially developed for this purpose, with the addition of a few specialised proprietary tools. In the first category are axes, hammers, chisels, shears and like tools ; and in the second, the various patented door breakers and padlock removers.

Large Axe. The axe used in the Fire Service is similar in design to that used by lumbermen in the Dominions, commonly known as a "felling axe." The materials from which it is constructed vary, but for perfect balance and rhythm in use the shaft should be shaped from a length of selected ash cut with the grain of the wood. The head is made from forged steel, sufficiently tempered to retain a fine cutting edge, and should be firmly secured.

It is important that the axe should be well made and perfectly balanced, and that the head should be secure, as it is frequently used at great heights from the ground and on narrow ledges, when a poorly balanced tool would be dangerous.

The large axe is used to break through wooden obstructions, doors, fences, partitions, etc., which impede the speedy application of water to the fire, or hinder rescue operations, and which are too substantial for the small axe carried on the belt. At least one large axe should be carried on all firefighting appliances in such a way that the cutting edge is protected from damage. Two large axes are issued with every emergency extra-heavy unit, heavy unit and large and medium trailer pump, and one with every light pump and escape-carrying unit.

Shears. The shears employed by the Fire Service are obtained from various machine tool manufacturers who stock them for engineering uses. They vary slightly in pattern, but, like the majority of small gear, are similar in essentials.

The type most generally used (Fig. 1) is similar in design to the shears used for pruning trees, but of exceptionally heavy construction, having short bills and long hand grips to give the necessary leverage. The bills usually work on a double fulcrum and are fitted with a release spring. In some cases semicircular slots are cut in each blade to enable the shears to be used as bolt cutters.

The shears are used for cutting padlocks and bolts to effect an entry into warehouses and other industrial places, which are usually protected by heavily bolted doors. They will not, however, be effective for certain types of padlocks which have case-hardened hasps. They can also be used for cutting wire fences which prevent the access of pumps to open water, and for a wide variety of similar purposes.

Routine maintenance of these tools consists of periodical inspection and cleaning and the application of a little oil as required. Shears will be found on some ex-regular emergency tenders and similar appliances but are not issued with emergency pumps.

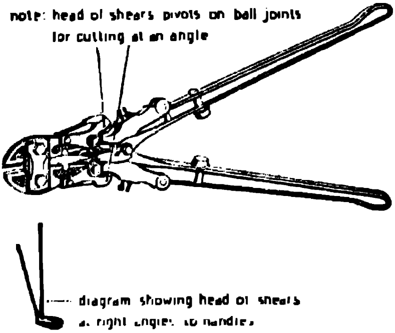

note: head of shears pivots on ball joints for cutting at an angle
diagram showing head of shears at right angles to handle

Fig. 1. Typical pair of shears with pivoted head for cutting at an angle.

Cold Chisels. Cold chisels of various types were widely used on ex-regular Fire Service appliances. They are similar in design to the steel chisels in common use, and vary in size from a few inches to a foot long.

The cold chisel is principally used in conjunction with a 4-lb. or 7-lb. hammer for cutting away concrete when dealing with hearth fires, and for removing fireplaces and bricks to provide access to defective flues and sometimes for cutting away stonework to free iron bars to windows or other openings.

Cold chisels are also used to effect an entry into buildings fitted with steel doors where shears cannot be used or are not available.

For this purpose the chisel is held on the head of the bolt securing the hinges and struck with a sledge hammer until the head of the bolt is sheared. When all the bolts have been sheared the hinge is wrenched off the door, either with the chisel or a crowbar, and the door released.

Routine maintenance of the tool consists of periodic inspection and cleaning, and re-grinding of the cutting edge when necessary.

Several sizes of cold chisels will be found on the majority of ex-regular appliances, but none are issued with emergency appliances.

Crowbars. Crowbars of various types form an essential part of the equipment of fire appliances. The most common type consists of a steel bar about 3 ft. in length, either one or both ends of which are shaped at an angle to provide leverage. One of these ends is usually divided so that the bar can be used for levering out nails, screws and similar fittings. Crowbars are used to provide the necessary leverage for all types of breaking-in and rescue operations. They should be stowed in the locker set aside for breaking in tools, and call for little maintenance other than routine inspection and cleaning as necessary.

Crowbars will be found on all Fire Service appliances. Two are issued with every emergency extra-heavy unit and escape-carrying unit and one with every heavy unit and trailer pump.

Hammers. Hammers of every size and type from the 14-lb. sledge hammer to the small ball-peine hammer issued with tool kits are carried on Fire Service appliances. The hammers used are the ordinary commercial type and need no maintenance other than routine inspection and cleaning.

They are used for a variety of purposes, the most common being in conjunction with cold chisels as described above. No hammers other than those issued with salvage tenders and with tool kits are carried on emergency appliances.

Other Breaking In Tools. In addition to the above standard tools, which are widely used for effecting a forcible entry to premises on fire, a variety of other tools, some patented by different manufacturers and some developed from the ideas of local officers, were used for these purposes by individual brigades. In this class come the innumerable shapes and sizes of bolt cutters (Fig. 2), padlock removers, door breakers, persuaders, levers and wedges of all kinds.

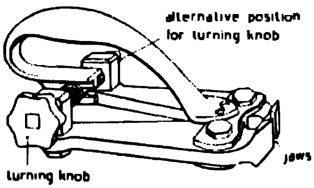


Fig. 2. Typical bolt cutter.

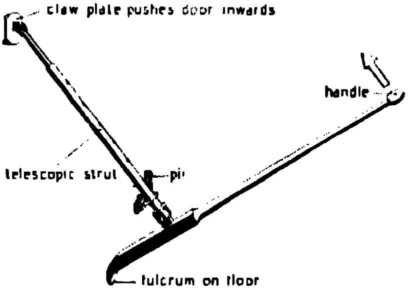


Fig. 3. Door breaker.

Some typical tools in this category are described below, but a wide range of similar tools, the innumerable variants of which it would be impracticable to describe, may be encountered on ex-regular appliances.

The use of such tools is, however, generally self-explanatory and their maintenance is the same as that described for other metal tools.

(i) *Door Breakers.* Several proprietary tools have been produced for breaking in locked doors. Although different in design and construction, all work by the application of the principle of leverage. A typical example consists of two steel bars of different lengths, the shorter being adjustable, joined in such a way that if the shorter arm is placed against a door, the application of force to the other arm exerts a tremendous pressure on the door panel (Fig. 3). Another type is inserted in the crack of the door and the application of pressure forces the door off its hinges. The "Alderman" or "Alexander" described under "Flooring Tools" (see later) can also be used to lift a door off its hinges by inserting the wedge-shaped end underneath the door and applying leverage. These devices are extremely effective, in some cases so much so that a police permit is necessary for their use, but they are not widely known and their use is restricted to a few ex-regular brigades. No such device is issued with emergency appliances.

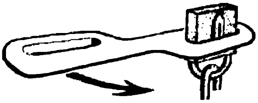


Fig. 4. Padlock remover, showing method of use.

(ii) *Padlock Removers.* The majority of ex-regular appliances carry some form of special lever or other tool, usually of local construction, to facilitate the rapid removal of padlocks.

A typical example of this type of tool is illustrated in Fig. 4. To operate, the lock is inserted in either opening and the other end is then turned so as to twist off the lock.

If no special tools are available padlocks can often be forced by wedging the hasp of the lock against the door with its hinge downwards and giving the body of the lock a sharp blow with a hammer.

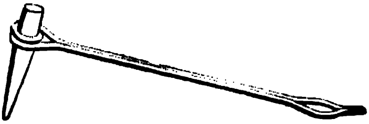


Fig. 5. Persuader.

(iii) *Persuaders.* A persuader is a form of cold chisel which has been specially constructed for the removal of locks the hasps of which cannot immediately be broken by means of a padlock remover, crowbar or other lever.

Fig. 5 shows a typical tool of this type, consisting of a tapering, cigar-shaped steel chisel, which is permanently secured in a wire holder. The chisel is not pointed, since its function is not to cut but to break the lock by the expanding effect of its being driven into the hasp. To operate, the chisel is inserted in the hasp and its head struck with a sledge or other heavy hammer until the lock is broken open.

2. CUTTING AWAY TOOLS

Cutting away tools consist in the main of the different types of saw, which are supplemented by chisels and files of various types and sizes. The distinction between standard and special tools mentioned in the section on breaking in tools applies with equal force to the cutting away tools, the saws being more or less standardised while a wide variety of tools is used for such specialised purposes as opening floorboards, cutting ventilation holes and similar operations.

Saws. A wide variety of saws will be found on Fire Service appliances. The standard issue on emergency appliances is a small double-edged panel saw about 18 in. long having rip teeth and tenon teeth, which is carried in a wooden case to prevent the teeth being damaged by other gear in the same locker. One of these saws is carried on every emergency appliance.

Ex-regular appliances may carry any kind of saw, including keyhole saws, tenon saws, large rip saws, hack saws and panel saws of every size. These are identical with the ordinary commercial tools and need no description.

A more specialised type is the saw used for cutting a hole in wooden floorboards, known as a floor or "cockerel" saw (Fig. 6) (from the resemblance between the blade of the saw and a cockscomb). This has a handle similar to the normal hand saw but is fitted with a convex-shaped blade which enables a lateral incision to be made without the previous use of an augur and keyhole saw. Another saw which has been specially designed for use in situations where there is insufficient space to operate the normal type, is the "chain" saw. This consists of a series of articulated links each of which is fitted with teeth. "T" handles are provided at each end, and the saw is operated by passing one end round the obstruction to be removed and pulling on each handle alternately.

Saw-blades should always be protected by a wooden or leather case to preserve the teeth, and the saw should, whenever possible, be stowed on hooks or in slots to prevent it being thrown about among heavy tools.

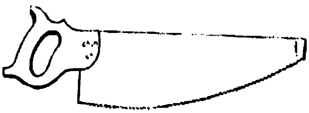


Fig. 6. Floor saw.

Saws call for little maintenance other than periodic inspection and cleaning. The blades should be given a thin film of oil to preserve them from rust and the teeth re-sharpened or reset when necessary.

Chisels. The type of chisels carried on ex-regular appliances, owing to the wide range available from tool manufacturers, depended entirely upon the preferences of the local officer. It is therefore impossible to give any description, or lay down sizes, which could be said to apply to more than one or two brigades. No chisels are issued with emergency appliances.

The chisels used, other than the cold chisels described with the other breaking in gear, were generally of the type employed for woodwork, and should need no description. Special chisels were, however, developed for use in levering up floorboards when dealing with hearth fires, or when ventilating a building.

Although the issue of chisels was not standardised, at least one, and probably several, will be found on the majority of ex-regular appliances. If chisels of the wooden-headed type are used a mallet will also be found on the appliance and should always be used with the chisel to prevent damage to the head.

The above tools comprise the cutting away gear normally found on ex-regular appliances. There are a number of other tools which may be encountered, the use of which is too restricted to justify their inclusion here. The following tools, however, although not generally issued, are carried on a fair proportion of ex-regular appliances.

(i) *Flooring Tools.* Several ex-regular brigades carried on their appliances complete sets of tools for removing floorboards. A set of such tools normally consisted of a floor saw, chisel, hammer and some form of special floor lever.

A typical example of this type of lever is the "Alderman" or

" Alexander " used by some ex-brigades. This consists of a wooden shaft about 3 ft. long on which is secured a steel wedge, so shaped that the pointed end can be used to prise up a floorboard, being driven in if necessary by a blow from a hammer, and leverage then applied to force out the board. Similar tools are also made with a steel shaft, the top of which has a crowbar tip.

(ii) *Hay Knives.* Ex-regular appliances covering rural areas often carry a special type of knife for cutting away the affected sections of burning hay ricks.

The knives used for this purpose have a wedge-shaped blade about 2 ft. long (sharpened on one edge only) on which is mounted a " T " handle. The blade is driven into the hay and worked up and down to cut away sections of the rick which can then be forked out.

A stone is usually carried for sharpening the blade as it loses its edge rapidly when used on hay.

(iii) *Miscellaneous Tools.* In addition to the above, a variety of miscellaneous tools for cutting away operations may be found on ex-regular appliances. These are generally ordinary commercial and industrial tools which were found valuable at one time or another by individual brigades, and their use perpetuated by custom.

Such tools comprise files, augurs, drills, brace and bit, and allied tools, the types and sizes of which differ too widely for any standard to be laid down.

3. RESCUE GEAR

The rescue gear carried on emergency appliances consists essentially of the standard 100-ft. line (or lifeline on turntable ladders) and whatever ladders are carried on the appliance.

Ex-regular appliances carry several items of specialised equipment for rescue work, the use of which, while not general, is sufficiently widespread to justify their inclusion in this chapter. The use of these various items of gear will be found fully described in the Chapter on " Methods of Rescue."

Rescue gear should, wherever possible, be carried externally on the appliance in quick-release satchels or containers. Where this is not practicable the most accessible locker should be used, and the gear stowed in such a manner that it is immediately available.

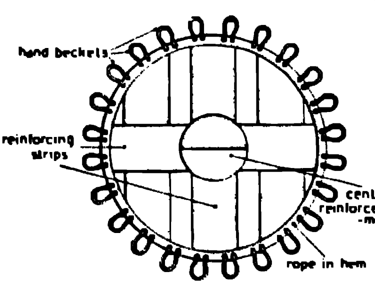


Fig. 7. Typical circular jumping sheet showing method of strengthening.

Jumping Sheet. A jumping sheet consists essentially of a circular or square sheet of canvas about 10 ft. across, fitted with a number of hand beckets spaced about 12 ins. apart round its edge. The construction, particularly in the method of strengthening, varies slightly. A typical example (Fig. 7) was made by hand from 24-in. widths of No. 1 canvas into a circle of 10 ft. diameter.

Two 24-in. strengthening bands of the same material were sewn across the diameter, and an additional centre piece 36 ins. diameter was also sewn in. The circumference was strengthened by a rope sewn into the seam of the canvas, and was fitted with 24 hand beckets spaced 12 ins. apart.

The jumping sheet should only be used when circumstances do not permit of the use of other means of rescue, or when it is feared that a person will jump down before a rescue can be effected by other means. It is an emergency appliance only, and extreme caution should be exercised in its use, which will be found fully described in the Chapter dealing with "Methods of Rescue." Apart from their normal function, jumping sheets are widely used as the most convenient means for the removal of bodies from fires. In some areas, however, special sheets, known as body sheets, are provided for this purpose.

Jumping sheets call for little maintenance other than periodic inspection. They should be thoroughly examined after use, whether for drills or at a fire, and if wet or damp should be dried thoroughly before being re-stowed. Much the same remarks apply to their care and maintenance as were made on the subject of canvas hose.

Jumping sheets are not issued with emergency appliances, but one will usually be found on all ex-regular appliances. They are normally carried externally on the appliance, ready for immediate use, in a special canvas bag provided for the purpose.

Brake Block. A brake block (Fig. 8) consists of a highly polished brass fitting in the form of a square figure 8, having at the top a projecting shoulder and a ring for attaching to the head of an escape or to a building. The object of the brake block is to check the speed of rope which is being used for lowering.

The brake block is secured in position by means of the ring, and one end of a line is led over each side of the shoulder and both ends brought up through the middle of the top part of the figure. This is known as a single lock.

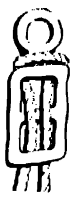


Fig. 8. Brake block used for checking the speed of a line rove through it. The illustration shows the line rove in a double lock.

If a double lock (Fig. 8) is required to give an additional braking effect, the lines are led over the centre bar and under the lower part of the figure.

Brake blocks will be found on many ex-regular appliances but are not issued with emergency appliances.

Rubber Gloves. Rubber gauntlets or gloves of various patterns are used by the Fire Service at fires and other occurrences where live electrical wires or apparatus are involved. Specifications vary considerably with the maker but most are tested to 15,000 v., though they should not be used on circuits exceeding some 3,300 v.

Their primary use is for rescue, as, for example, to extricate a person who is in contact, or suspected of being in contact, with electrical apparatus. They may sometimes be used by branchmen when the use of water on electrical apparatus is unavoidable.

Rubber gloves should also be worn when dealing with electrical fires on tramcars, as the control panels at each end of the lower deck usually carry about 600 v.

Rubber sandals which are designed to slip over leather fire boots are also used in some areas as an additional precaution when wearing rubber gloves or gauntlets. In other localities a rubber mat and sometimes special rubber boots are also carried to give additional protection when using the gloves or gauntlets.

Rubber gloves are carried on ex-regular appliances only, and have not been issued with emergency appliances.

Rubber gloves are normally stowed, covered with french chalk to preserve them, in airtight metal containers. Little maintenance is therefore necessary and, in fact, the less they are handled the better. Arrangements should, however, be made for testing at regular intervals by the manufacturers.

Asbestos Equipment. The application of asbestos to firefighting is at present largely confined to the use of asbestos blankets and gauntlets for smothering carburettor fires and other similar outbreaks.

A certain number of these blankets and gauntlets have been issued to the National Fire Service for use with foam branches to protect firemen working at oil fires on account of the relatively short distance at which it is necessary to work when using foam.

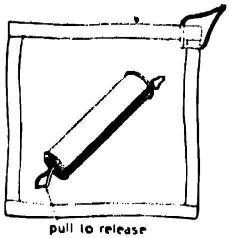


Fig. 9. Asbestos blanket, showing method of stowing in tubular container ready for immediate release.

These blankets (Fig. 9) are made from asbestos cloth in squares of from 3 to 6 ft. and are sometimes carried in tubular metal containers or quick-release satchels. The use of blankets of this type is not standardised, but at least one will be found on the majority of ex-regular appliances.

The only other service application of asbestos is the use of complete suits which protect the whole body and allow the wearer to venture for a limited time into the heart of the fire itself. These suits are principally used on airfield fire tenders to assist in the rescue of personnel from burning aircraft. A limited number of service appliances which cover airfields also carry these suits, but their issue is too restricted for them to be regarded as in any way a standard item of equipment.

Asbestos suits are either of the all-in-one type, comprising a helmet, coat and boots, or in three pieces, consisting of a separate helmet, coat and trousers. The suits are extremely hot and heavy to wear and, once the visor in the headpiece is closed, the wearer has to rely on the air inside the suit only for his supply. It is considered that two minutes is the maximum time during which one of these suits can be worn with safety in a heated atmosphere and then only by a trained and thoroughly fit man. Any general application of such suits to firefighting is therefore out of the question.

Quick Release Knives. A special type of knife is sometimes carried on appliances which may be called to fires in crashed aircraft. It consists of a strong sheath knife, the blade of which is sharpened to a razor edge on one side and rounded on the other. The knife is used in emergencies to cut the safety belts which secure the crew in the aircraft. It is inserted inside the belt with the blunted side against the airman's body.

Other Rescue Gear. There are, of course, other items of rescue gear to be found on appliances which are not described above. These are such items as hook ladders and ladders generally, turntable ladder slings and lowering and life lines, all of which have been described in earlier chapters.

4. LIGHTS

Perhaps the greatest variation in small gear between former brigades was in the types of lights carried for use in firefighting and at other occurrences. Every type of lamp from oil lamps to powerful electric searchlights and floodlights has been adapted for Fire Service use and it is difficult, therefore, without describing individual types at great length, to give details which will apply to the Service generally.

In the main, the lights used in the Service may be roughly classified as :—

(*a*) Electric hand lamps of various types.
(*b*) ,, box lamps ,, ,, ,,
(*c*) ,, searchlights and floodlights of various types.
(*d*) Dissolved acetylene and carbide lamps.
(*e*) Oil lamps.

(*a*) *Electric Hand Lamps.* The electric hand lamps used by the Service fall into two main types :—

(i) the ordinary commercial hand lamp with a dry battery, made in various patterns ; and

(ii) special lamps, some adapted from those used in mines, of greater durability and provided with a rechargeable battery or accumulator, these latter being usually known by a proprietary name.

(i) *Emergency Hand Lamps.* These call for little description, consisting essentially of a metal case fitted with a bulb holder, and using the ordinary commercial dry battery (Fig. 10 (i)). They are used for a variety of purposes, and may generally be described as an individual lamp for short period use.

(ii) *Proprietary Hand Lamps.* Various types are used in the service with breathing apparatus, and on other occasions when sustained light is required.

One of the most popular of this type of lamp consists of a japanned metal case in which is fitted a 2-v. accumulator of 7-ampere hour capacity. (Fig. 10 (ii)). The case is fitted with an adjustable reflector, and in some models provision is made for carrying a spare bulb. Contact is made by means of an external rotary switch on the top of the case. This lamp is characterised by careful attention to design but suffers from the disadvantage, from the point of view of breathing apparatus work, that it is not gas-tight.

It is essential that any lamp used by breathing apparatus men should be gas-tight, since work will at times have to be undertaken under conditions in which any accidental and exposed spark from a faulty contact or other cause would be dangerous. The lamps used by breathing apparatus men have for this reason been largely developed from those used in mines.

These lamps consist in essentials of a circular metal, or composition, container in two portions, which are joined by means of a screw thread or bayonet type joint. The lower portion contains a 2 or 4 v. accumulator of from 5 to 7 ampere-hours capacity, and the upper portion comprises a sealed bulb holder and reflector. The divided construction enables the light to be switched on or off by means of rotating contacts which are operated by turning the head of the lamp. An internal switch of this type is an essential feature of a gas-tight lamp since an external switch would be impracticable. A typical example of this type of lamp is shown in Fig. 10 (iii).

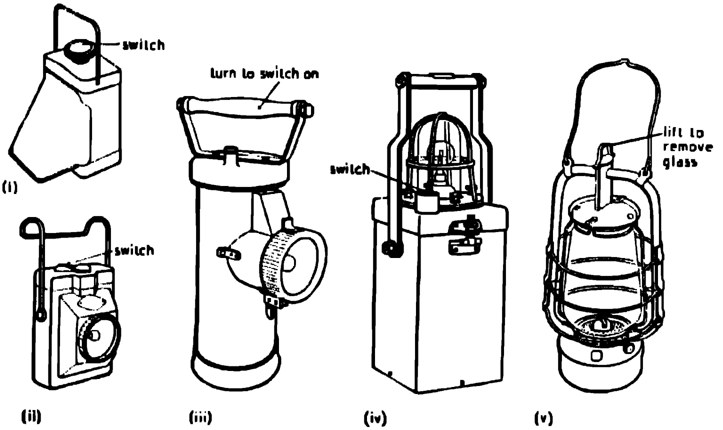


Fig. 10. Typical hand lamps: (i) emergency type battery hand lamp; (ii) proprietary rechargeable accumulator hand lamp; (iii) typical breathing apparatus lamp; (iv) electric box lamp; (v) emergency type hurricane lamp.

Another type of lamp which has been primarily developed for use by breathing apparatus men consists of an accumulator hand lamp in which is incorporated a buzzer alarm. When the light is switched on the buzzer comes into operation, and a contact must be held down to prevent it sounding. Consequently, if the man is overcome by fumes and drops the lamp, the alarm sounds and a warning is thus given that help is required. This type of lamp suffers from the disadvantage that it puts one hand out of action for any useful work. It is therefore admirable for preliminary exploration or inspection of smoke-logged premises, but is of little value for prolonged operations.

All these special types of hand lamp may be found fitted with either shoulder straps or spring clips for affixing to the belt.

Accumulator type lamps should be tested daily to ensure that they are available for use. The accumulator should be removed weekly for examination and recharging if necessary. All contact points, terminals and other metal parts should be kept scrupulously clean and a light film of vaseline applied to prevent sulphation by creepage of acid.

There is no standard issue of accumulator type hand lamps to appliances. At least one lamp of this type will, however, be found on the majority of ex-regular appliances, and their issue for use with breathing apparatus has recently been approved. The scale of issue will be one per set of breathing apparatus. The type of lamp which has been adopted is illustrated in Fig. 11. It will be seen that the lamp consists of a container of the type described above, constructed from copper, and having solid brass joint rings. The lower portion of the container houses a 2 v. 8 ampere-hour jelly-acid accumulator, and the upper portion a highly polished bull's-eye type reflector, fitted with a focussed bulb. The lamp is gas- and water-tight, and is fitted with a carrying handle and hook. The total weight is 2 lbs. 12 ozs.

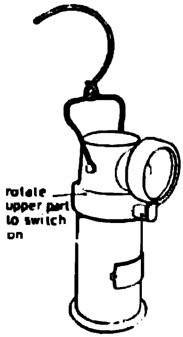


Fig. 11. Breathing apparatus lamp.

(*b*) ***Electric Box Lamps.*** Electric box lamps consist of a metal or wooden case containing an accumulator of from 2 to 6 v. capacity and having an electric bulb in a protecting cage, either on the top or on the side of the container. (Fig. 10 (iv.).) The box lamp is used where sustained illumination is required for a period over which it would be uneconomical to use a hand lamp, such as to light up rooms, stairways, etc., in buildings in which the normal lighting has failed.

It is extremely valuable when working in dark and difficult conditions, as owing to its weight, construction and general stability it can be left standing in the middle of a room, thus leaving both hands free for other work.

Box lamps should be examined weekly and the battery removed and topped up with distilled water as required. All terminals and surfaces on which electrolyte has been spilled should be wiped clean with a rag damped with a solution of washing soda in water, particular attention being paid to the removal of verdigris from terminals, surfaces and screw threads. After all verdigris has been removed, the terminals should be given a light smearing of vaseline to prevent corrosion by acid, but not sufficient to accumulate dust. The battery should then be tested with a hydrometer to ensure that it is fully charged and, if necessary, recharged.

The use of box lamps was not standardised but one at least will normally be found on almost all ex-regular pumps, special service tenders and similar vehicles. They are not issued with emergency appliances.

Electric Searchlights and Floodlights. The electric hand lamps described above are designed to provide restricted illumination over a small area, and are generally used inside buildings. In normal times as much light as possible should also be provided on the fire ground itself, to assist in the marshalling of appliances, the recognition of officers, and firefighting operations generally. Electric searchlights and floodlights are generally used for this purpose, having largely superseded the dissolved acetylene and carbide lamps which were once universal.

An electric searchlight consists of a single filament lamp mounted in a reflecting container. Some form of swivelling and focussing adjustment is usually provided, and the lamp may be either mounted on the appliance or on a self-contained tripod, in which latter case a reel of heavily insulated rubber wire is also carried.

Special service tenders occasionally carry an extremely powerful searchlight fitted with high-voltage bulbs, requiring a current in the neighbourhood of 25 amperes at 100 v., and consequently cannot be operated adequately from the ordinary accumulator carried on the appliance. The requisite power is provided by a many-celled battery and suitable voltage dynamo specially fitted to the tender. This dynamo is also used to provide current for other power-driven equipment such as drills, smoke exhausters, etc., through a special switchboard. Provision is also frequently made either for the lamp itself to be plugged direct into the town's electrical supply, or for connection to be made between this supply and the switchboard.

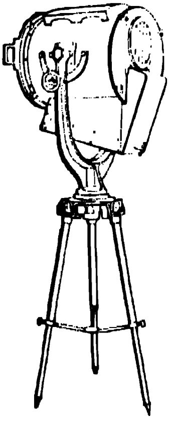


Fig. 12. Typical searchlight, as used by an ex-regular emergency tender.

Such high power searchlights may also be fitted with an arc lamp in place of the electric bulb. A typical lamp of this type is illustrated in Fig. 12.

The body of this lamp is constructed of light sheet steel, with fittings of gun-metal and aluminium. The tripod is constructed from telescopic steel tubing. A current of 25 amperes at 100 v. is required to operate the lamp, which has an effective range of 500 yards, and provides a light of 5,000 to 6,000 candle-power, according to the angle of dispersion of the beam.

Smaller searchlights, similar to motor-car headlights or spotlights, are also widely used; a typical example being the searchlight mounted at the rear of a turntable ladder. These lights, being of smaller capacity, are usually operated direct from the accumulator normally carried on the appliance. They also may be mounted on a tripod and fitted with wandering leads to allow them to be moved about within a convenient range of the appliance.

The necessity for providing intense illumination on the scene of large fires has led to the local development of many extremely efficient and inexpensive floodlights, which, while not producing the powerful and penetrating beam of a searchlight, give brilliant and sustained illumination over a wide area.

A typical example of this type of lamp is the " Cluster " lamp, used by one former brigade on its fireboats. This consists of a simple metal reflector, on which are mounted three ordinary electric light bulbs, the whole being protected by a wire cage. A handle is mounted on the back of the reflector by which the light is hung from any convenient object, current being supplied from accumulators carried on the fireboat.

Dissolved Acetylene and Carbide Lamps. Before the introduction of high-powered electric searchlights and floodlights, the intense illumination required on the scene of large fires was invariably provided by acetylene lamps, of the type frequently known as " contractor's lamps." Although these have now largely been superseded by the electric lamps described above, dissolved acetylene and carbide lamps of various types may still be found on ex-regular pumps, emergency tenders and similar appliances.

Acetylene lamps fall into two categories. The first type consists of lamps supplied by cylinders of compressed acetylene gas , since highly compressed acetylene is extremely unstable and explosive, the gas is dissolved in a liquid in the cylinders (normally acetone) which renders it safe. It is for this reason that acetylene in cylinders is normally known as " dissolved acetylene." The second type is supplied by acetylene gas made as required by allowing water to act on carbide.

Dissolved acetylene lamps vary greatly in dimensions and design but are all constructed on the same basic principle, consisting usually of a cylinder or other container to which is attached a metal pipe supplying a burner fitted with a reflector. The cylinder contains a quantity of dissolved acetylene the supply of which is controlled by a main valve fitted on the head of the cylinder. There is usually also a small regulating cock at the rear of the burner to adjust the pressure of the supply. A typical lamp of this type contains 60 cu. ft. of acetylene which is consumed at the rate of 6 cu. ft. per hour, thus giving ten hours burning. It gives a 10,000 candle-power light. A smaller size contains 12 cu. ft.

When possible, this type of lamp should be carried on the appliance with the container and burner, which are usually joined by screw connections, detached. Before getting to work the joints must therefore be remade and it is essential that a gas-tight joint be effected ; this can be tested by smelling the joint after the main valve has been turned on. The regulating cock should then be adjusted to give the minimum pressure necessary to dispel the smoke emitted from the flame.

Dissolved acetylene lights have also been used with searchlight type reflectors. The range of these lamps, however, is considerably less than the electric type—a typical reflector gives an effective beam of 400 ft. when fitted with a single filament electric bulb, and only 200 ft. when fitted with an acetylene burner.

Carbide lamps give similar results to the dissolved acetylene lamp described above, but, being an older pattern, usually produce a light of less candle power. They normally consist of a cylindrical container which is filled with water, and in which is an inner compartment containing carbide of calcium. A burner and reflector similar to that fitted with the acetylene lamp are attached to the top or side of the container.

Carbide lamps are carried on the appliances empty. When the lamp is required, the carbide container is filled to about one-third of its capacity, and the water container filled. The water should be replenished as necessary while the lamp is burning.

Carbide lamps should be inspected periodically to ensure that both containers are perfectly clean and dry. The burner should be cleaned immediately after use by means of a very fine wire. If too large a wire is used, and if the burner is roughly handled, there is a danger of the hole being enlarged, when a smoky flame will result. It is advisable to carry a spare burner, and this can conveniently be kept in one of the calcium carbide tins.

No acetylene lamps are carried on emergency appliances. Many ex-regular brigades, however, use these lamps on account of the brilliant light they provide at a low cost. The principal defect of the carbide type is that it is liable to be extinguished in high winds or draughts. Various devices have been designed for automatically relighting burners but these are not entirely successful.

Carbide lamps have an added disadvantage in that there is frequently delay in getting them to work, owing to the necessity for first charging the containers and then waiting until a sufficiency of acetylene gas has been produced. Prior to nationalisation, carbide lamps were being rapidly replaced by electric searchlights and floodlights, which, besides being more convenient and reliable in operation, gave a more penetrating light.

Oil Lamps. Although small oil lamps are still used for such purposes as rear lights on trailer pumps and other appliances not provided with a battery, the majority of the many lights of this type formerly carried on Fire Service appliances have been superseded by electric and acetylene lights, the only survival of these early types being the still popular hurricane lamp. An incandescent type paraffin floodlight has, however, been produced which has achieved considerable popularity, particularly in rural areas, on account of its economy and independence of external power supply.

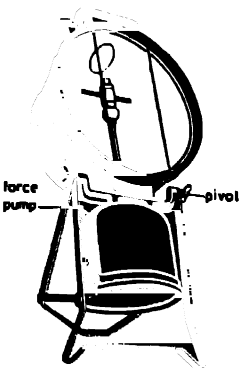


Fig. 13. Floodlight using vaporised paraffin in conjunction with incandescent mantle.

This floodlight (Fig. 13) consists of a 14-in. chromium-plated reflector in a strong steel casing, mounted on a 6-pint circular oil container. The container is fitted with a pressure gauge, oil level indicator and a small force pump similar to those used on primus stoves.

The light is operated in the same way as a paraffin stove by working the pump until sufficient pressure is raised in the container to cause the oil to flow from a vaporiser which is mounted in the reflector, and is fitted with a removable mantle.

A light of 5,000 mean reflected candle power is given and the container holds a supply sufficient for forty continuous burning hours. The lamp is usually mounted on a small metal stand as shown in Fig. 13, but may also be mounted on a tripod, or a special turntable for fixing on an appliance.

A few oil lamps of older pattern, such as the duck lamp or fog flare, may still occasionally be found on ex-regular appliances. These, however, have an academic interest only, as survivals of a now generally obsolete practice, and a description is not therefore included in this chapter.

Hurricane lamps vary slightly in design, but the construction is the same in each case and has changed little in the past century. The lamp comprises a simple oil burner, the flame of which is protected by a glass funnel mounted on a circular base holding about a pint of paraffin oil (Fig. 10 (v)). A metal lid containing ventilation holes which permit the exit, but not the entry, of air is fitted on top of this funnel, thus providing a partially sealed compartment in which the light will continue to burn in the highest wind.

Hurricane lamps are used for a variety of purposes, principally for marking hose ramps, hydrant pits and similar obstructions and for indicating the position of steel dams and other emergency water supplies when these are situated in public places. They also provide a valuable emergency lighting supply for stations and other purposes.

Hurricane lamps should be stowed in an upright position, preferably in a separate compartment. They should never be stowed with hose, especially rubber lined hose, as any leakage of oil would result in damage to the hose.

They should be cleaned, replenished and the wicks trimmed each time after use.

Hurricane lamps are carried on all emergency Fire Service appliances.

5. TURNING OVER TOOLS

Turning over tools are those used after an outbreak of fire has been subdued to break up and disperse the burning materials. The object of this operation is not only to enable water to reach any burning embers which may remain, but also to assist in extinguishing the fire by the principles of sub-division and cooling described in Chapter 2.

Almost any tool can be used for turning over, such items of equipment as crowbars, axes, levers and other breaking in or cutting away tools having obvious applications. Apart from the fireman's axe, tools which are primarily employed for turning over are the steel-shod wooden lever, ceiling hook, pick, mattock and spade.

Ceiling Hook. The ceiling hook (Fig. 14) consists of a pole from 7 to 8 ft. long, having at the top a steel point with a spur at right angles, the point and spur being each about 4 ins. long.

This tool is of interest as being one of the few items of small gear which were primarily developed for Fire Service use. Its relationship to the boat-hook is, of course, obvious, but in its present form it is exclusively a Fire Service tool.

The ceiling hook is now most commonly used to pierce a ceiling to allow water to escape and thus prevent water damage generally and the possible collapse of the ceiling itself due to the weight of water.

The spur is used for pulling down ceilings which have partially fallen and are in a dangerous condition. The hook is driven up through the ceiling, and the spur twisted until a grip is obtained on any projecting laths. A sharp pull will then bring down a portion of the laths and plaster, and the operation is repeated until the ceiling is considered safe. The same procedure may also be followed for pulling down lath and plaster walls.

The ceiling hook, owing to its length, is a general purpose tool of great value. It is used for all turning over and pulling down from difficult or inaccessible positions, and for any job calling for a long reach with a rigid piece of equipment. A common example of the latter is its use for operating the "fireman's switch" on high voltage lighting apparatus, such as neon signs. These switches are usually located about 8 ft. from the ground to prevent interference by unauthorised persons.

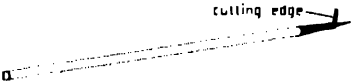


Fig. 14. Ceiling hook.

Owing to its length the ceiling hook is usually carried strapped alongside the escape or other ladder, or on the body of the appliance. Routine maintenance consists of periodic inspection and cleaning when necessary.

At least one ceiling hook will be found on almost all ex-regular and all emergency Fire Service appliances.

Picks. Picks or mattocks are an essential item of turning-over gear. Ordinary commercial tools are used.

A pick consists of a wooden shaft about 3 ft. long, having a crescent-shaped steel head about 2 ft. 6 ins. long, each end of which is dressed to a sharp point.

A mattock is a similar tool having one end of the head pointed and the other spade shaped.

Picks and mattocks are used for turning over and general utility work, and will be found on virtually all Fire Service appliances. They need little maintenance other than routine inspection and cleaning.

Spades. A general purpose tool calling for little description and principally used for clearing away débris to enable water to reach the seat of the fire or to ensure that all heat is dissipated when turning over. It may also be used to make temporary dams when drawing water from shallow rivers or streams.

Routine maintenance consists of periodic inspection and cleaning as necessary. The scale of issue is the same as for mattocks.

Steel-shod Wooden Lever. The steel-shod wooden lever consists of a straight wooden shaft about 2 ins. diameter, increasing to a square of about 3 ins. at one end to which is secured a heavy metal fitting in the shape of a lever (Fig. 15). The lever is used for breaking open steel doors and other obstructions, the tip being inserted under the door and leverage exerted. It is also used for lifting blocks of stone or concrete, heavy baulks of timber, and other material when turning over. It requires little maintenance other than periodical inspection and cleaning when necessary.

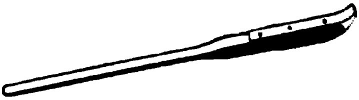


Fig. 15. Steel-shod wooden lever.

Stack Drags. Various tools are employed in different localities to assist in pulling apart haystacks, tearing down thatched roofs, and similar rural or agricultural hazards.

A typical tool of this type is the stack drag. This consists of a fork which has a hook set at right angles to the shaft. The shaft, which is usually about 12 ft. long, is sometimes made of metal to prevent it being damaged by fire.

6. TRANSPORT TOOLS

A sufficient tool kit to carry out routine maintenance and to deal with minor roadside breakdowns should be carried on every Fire Service vehicle. It is particularly important that a jack and wheel brace should be carried, and that the spare wheel be kept in good condition. It should not be necessary to detail the other tools, which should be familiar to every driver. A good basic kit might consist of grease-gun, screwdriver, shifting spanner, magneto spanner, set spanners, plug spanner and tommy bar, ball peine hammer and a pair of pliers.

Tool kits should be checked at regular intervals to ensure that all tools are intact and in good condition. Transport tools should be stowed together in a small and not too accessible locker and should never be borrowed from an appliance without the driver first being informed.

Other items of small gear associated with the maintenance and operation of appliances are heater lamps, skid chains and tow ropes.

Heater Lamps. Heater lamps are very usually employed with appliances which are not fitted with immersion heaters or other automatic heating devices, unless they are garaged under cover. They are constructed on the same principle as the miner's safety lamp and consist of an oil burner mounted on a metal base containing about a pint of paraffin surrounded by a gauze mesh screen to prevent the flame igniting any petrol vapour which may be present.

Throughout the winter months heater lamps call for regular daily maintenance. A routine of inspection, cleaning and replenishment as required should be established, particular care being taken that the oil reservoirs are filled and wicks trimmed before dusk each night.

A notice should be prominently displayed on each appliance that a heater lamp is in use, to ensure that the lamp is removed before the engine is started. This is of equal importance in the case of such appliances as trailer pumps, since the lamp may fall out on the journey or the base become detached from the top and the part be lost.

During the summer months heater lamps should be emptied of paraffin, cleaned and put away in store, clearly marked with the number of the appliance to which they belong.

Skid Chains. Skid chains are a necessary item of equipment in districts where heavy falls of snow are usual. In these areas they should be carried on all first-call appliances, and in other areas a small stock should be held for issue when necessary, as, for example, when reinforcement units are ordered into areas which are known to be snow bound.

Two principal types of chain are in use. The most common consists of two circles of steel chain, joined at intervals by short lengths of chain, which are secured on either side of the tyre. The second type consists of short lengths of chain which are secured by means of straps round the tyre and wheel rim, four being usually fitted on each wheel. It is usual to fit skid chains on rear wheels only but for complete safety all four wheels should be fitted.

Tow Ropes. All Fire Service appliances should carry a short length of strong rope, which can be made from the sound parts of condemned lowering or other stout line for use as a tow rope. The availability of such a rope will prevent the use of rescue or other lines for this purpose if an appliance becomes disabled.

A number of the early trailer pumps were issued with two short lengths of stout rope fitted with a galvanised iron hook at one end. These ropes were intended to assist in manhandling the pump, and not for towing by another vehicle. Their use for this latter purpose, generally by clipping the hook round the axle of the vehicle, has already damaged a large proportion of these ropes, and should not be permitted.

Later models of trailer pump have not been issued with these tow ropes, which cannot, therefore, be regarded as standard equipment.

7. MISCELLANEOUS AND SPECIAL EQUIPMENT

In addition to the various types of equipment described above there are several items of small gear carried on Fire Service appliances which are difficult to classify, but call for description as they are likely to be encountered on any appliance. Some of these items are widely used, others, although approved in principle, have at present only a restricted issue, and others are confined to certain areas.

Canvas Buckets. Collapsible canvas buckets of capacities varying from 2 to 4 gallons are carried on the majority of Fire Service appliances. They have many uses, the principal of which is to supply water for stirrup or other hand pumps. Their great advantage is that they occupy a minimum amount of space and several of them can be stowed compactly together in a very small locker. Canvas buckets should be thoroughly dried after use before being stowed away to prevent the formation of mildew. Much the same remarks apply to their care and maintenance as were made in the case of hose.

At least one canvas bucket will be found on every Fire Service appliance.

Fire Bats. A fire bat consists of a wooden or flexible shaft, approximately 3 to 4 ft. in length, at one end of which is secured a piece of reinforced canvas about 18 ins. long and 9 ins. wide (Fig. 16). Fire bats are used for beating out heath and grass fires and are carried on many appliances in rural districts. Many types will be found; numbers of which have been made locally from old pieces of discarded hose. No fire bats are issued with emergency appliances.

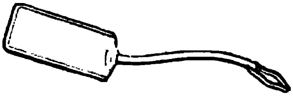


Fig. 16. Fire bat.

Trolley Bus Short-circuiting Gear. The trolley bus short-circuiting gear (Fig. 17) is a piece of specialised apparatus for use in towns in which trolley buses are extensively employed, to enable the Fire Service to cut off the current from the circuit when escapes or other ladders have to be used in the vicinity of the wires.

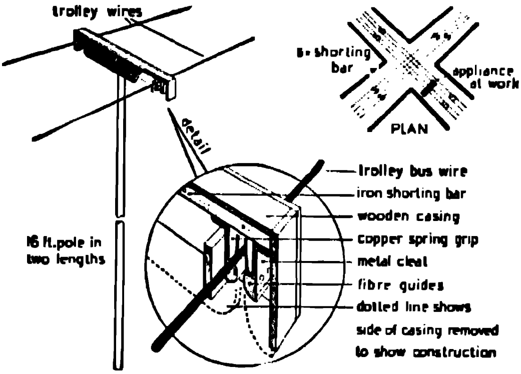


Fig. 17. Trolley bus short-circuiting gear, showing detail of construction, how fitted to the trolley bus wires and the correct siting of sets of gear at a road intersection.

The apparatus consists of :—

(i) A shorting box comprising a 2-ft. iron bar having copper contacts inset in slots at each end which are protected by fibre-insulating blocks supported on springs. To enable safe contact to be made with live wires the bar is enclosed in a hard-wood insulating case, which is fitted with slots at each end to guide the wires on to the copper contacts.

The object of the spring-mounted fibre blocks is to allow the device to register correctly on the wires without making electrical contact. When the box is in position a small amount of force is applied which opens the springs and allows the wires to connect with the copper contacts.

(ii) Two 6-ft. bamboo poles, one of which screws into the shorting arm by means of a brass right-hand screw stud and which can be connected together by a left-hand screw stud or in some cases by sliding brass sockets.

(iii) Two 6-ft. rubber insulating strips and

(iv) A device for threading these strips on to the trolley bu wires.

To operate this gear the top section of the pole is screwed into th shorting bar and the sections joined. The box is then raised betwee and above the two wires, turned, and lowered to form a bridge, wi the fibre protecting blocks resting on the wires. A sharp pull to ea side will then complete the contact, thus short-circuiting the wir

When the wires are shorted a circuit breaker in the electric sub-station supplying the circuit opens and cuts off the current.

There is on the majority of these circuits, however, a device know as a re-close relay which comes into operation automatically wh the circuit is broken and attempts to remake it. This devi operates three times over a period of approximately five minutes a then cuts out. It must not, therefore, be assumed that the curre is off until at least five minutes after the circuit is broken.

As an additional precaution the electrical sub-station supplyi the current should be informed as soon as possible. This is parti- cularly important when only one set of shorting gear is available a it is necessary to remove the box after shorting each line in turn.

Appliances which carry the shorting gear are usually provi with a key to the door on the feeder pillars which supply the curr to the line. A telephone will frequently be found behind this d with a chart giving instructions how to inform the electrical station that the line has been shorted.

If no telephone is provided the address and telephone numb the sub-station will be found printed inside the door, and should be taken immediately to get in touch with the engi n order to prevent him restoring the current over lines from ch the shorting box has been removed.

The following points should be borne in mind when using the trolley bus shorting gear.

(*a*) Even the 12-ft. pole will normally be insufficient to reach the overhead wires and it is therefore usually necessary to stand on a pump or other appliance. Care should be exercised when manœuvring an appliance into position that any projecting part does not come into contact with the wires.

(*b*) Trolley bus overhead wires are supplied with current by means of independent circuits fed from roadside pillars. These circuits are normally about half a mile in length. If one shorting box only is employed, although the current may be cut off on one circuit, another circuit may still be functioning in the vicinity of the fire. Two boxes should therefore be employed, one on each side of the fire.

(*c*) The up and down trolley bus wires are frequently supplied by separate circuits and it is necessary, therefore, to short-circuit both these sets of wires to effect a completely safe break; four boxes should, therefore, be employed to achieve complete safety.

(*d*) If the fire occurs near cross-roads or at the junction of several roads, the current may be supplied to any one point from a number of circuits. To ensure complete safety under these conditions, shorting boxes should be used about 25 yards down each road on nich trolley buses are used. The plan in Fig. 17 (*top right*) shows e positions of the boxes in such circumstances.

(*c*) If a large number of boxes are required and only one is avail- le, the procedure should be to apply the shorting box within a few t of the fire and as soon as the circuit is broken thread on the ber insulating strips to cover the area where ladders are most ly to be employed. The box should then be removed and applied cessively on each circuit, being left on each a sufficient time to event the re-close relay operating.

Trolley bus shorting gear calls for little maintenance other than iodic inspection and cleaning. All metal parts are of brass and rust should therefore occur.

The gear is not a standard item of equipment but is carried on a nber of ex-regular appliances and on all emergency escape- rying units in certain Regions.

Asbestos Screens and Shields. Although asbestos is little used the Service, its application to industrial firefighting has been lely developed.

mong the items of equipment sold for use by industrial or lian fire squads are asbestos face protectors, fire shields and bile screens.

sbestos fire shields vary in size from small squares of 2 ft. to 6 ft., may consist of simple square shields built up on a light metal ework, or of elaborate three-sided shelters fitted with visors n aperture for the branch.

bile asbestos screens consist of large sheets of asbestos cloth r ed on a metal framework supported on b wheels. They are used to shield objects wh cannot immediately be moved, such as larg ums of oil, from the effects of radiant heat and ng sparks.

Although not carried on Service appliances, many of these types of asbestos equipment may be encountered in factories and other industrial buildings and their use should therefore be understood so that when found they may be employed to the best advantage.

Chimney Rods. It has been explained in the Chapter on "Hand and Stirrup Pumps" that the recognised method of dealing with chimney fires is by means of a hand pump, the nozzle of which is attached to chimney rods and pushed up the chimney. The rods (Fig. 18) consist of a series of stout but flexible malacca canes with screw joints at each end closely resembling a sweep's rods. The first cane, to which the nozzle is attached, is fitted with a small roller at the head to prevent it catching on any roughness in the interior of the chimney. After the first section has been pushed up the chimney further canes are added as necessary to the required height.

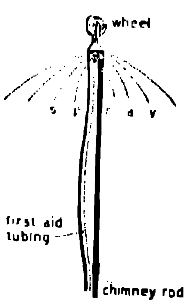


Fig. 18. Set of chimney rods. Note the roller on the first section to prevent catching in the chimney.

Medical First Aid Outfit. A first aid outfit should be carried on every Fire Service appliance in order to provide urgent first aid treatment not only for the crew but for members of the pu may be found injured at fires.

The contents of these outfits vary widely on the e appliances, being obtained in most cases by local pur required, but a standard issue has been laid down for the j metal first aid cases carried on all emergency applianc consists of :—

Item	st
Triangular bandages, 36-in. base	
2-in. roller bandages, 4 yds.	
Sterilised dressings, 8 ins. × 6 ins.	
Medium sterilised dressings, 4 ins. × 4 ins.	
½ oz. packets, absorbent lint, 15 ins. × 6 ins.	
2-oz. packets, cotton wool	
Wooden splints, 12 ins. × 2½ ins.	
Piece, birch dowel, 6 ins. × ½ in.	
4-oz. bottle bicarbonate of soda	
1-oz. container 2 per cent. alcoholic solution of iodine	
Ampoules, aromatic ammonia	
Safety pins	
Cotton web straps, 42 ins. × ½ in.	
Scissors	

First aid kit should be examined at regular intervals individual items inspected for any signs of deteriorati contents should be checked weekly and any deficiency m

Miscellaneous Tools. There are two items normally in the kit of transport tools which can with advantage be du the second one being carried in a more accessible positi th appliance. These are a medium-sized shifting spanner an pai of insulated pliers.

A shifting spanner is often useful, a particular use being to tur off gas mains below the meters by means of the squared cocks This type of cock should be provided with detachable handles, bu these are often missing and a shifting spanner then becomes essentia unless, as is sometimes the case, a key is carried on the appliance fo this purpose.

A large pair of adequately insulated pliers is also of great assistanc when working on electrical fires, and if available should be kep handy instead of being tucked away (and probably forgotten) in th tool box.

NOTE

As was explained at the beginning of this chapter, the small gea carried on Fire Service appliances varies widely in each area, though usually on minor points. The items described abov should therefore be taken as representative of the different types of gear carried, and not as a comprehensive survey covering every individual piece of equipment.

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freshened up a bit—whether 't hen did they see the
getting away from home or light. Knight instantly
perhaps, I may as well s as Lord Luxellian, the
that her home was no ho ide.
was bitter to her and es to be intruders. Knight
Mrs. Swancourt was , and they silently withdrew as
a sort of cold politen
the little thing,' he said, in a broken voice. 'We
About a mor to be there. Another stands before us
and the tw her than we!'
hors nd side by side they retraced their steps down
the grey still valley to Castle Boterel.

THE END

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